CRANIOFACIAL MORPHOLOGY IN SUBJECTS WITH ADVANCED DENTAL ATTRITION

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A thesis for submission to fulfil the requirements of the University of Edinburgh for the degree of Doctor of Dental Surgery (DDS).

ABSTRACT

The present study identifies the differences in hard and soft tissue craniofacial morphology that may be found in the presence of advanced dental attrition and ageing when detailed linear and angular cephalometric comparisons of a study sample (N=35, mean age 48.4 years) were made with a control group of young adult subjects (N=40, mean age 26.1 years), using computer based recording and measurement apparatus.

Existing computer programmes were modified for the purpose of the present study to enable the recording of 51 defined sequential radiographic points, producing 32 linear and 21 angular variables of craniofacial form for each subject.

Method error determinations were carried out for both digitiser and cephalometric variables. X and Y co-ordinate identification accuracy, linearity of the digitiser table and cursor and point placement error by the operator were examined statistically with an analysis of variance, using skewness and kurtosis parameters to ensure the elimination of any distribution errors prior to t-test comparisons between the study sample and the control group.
Comparisons were made between hard and soft tissue measurements for the study sample and the control group and the statistically significant differences tabulated.

The results of the study showed marked linear and angular differences in craniofacial morphology between the categories. In

the presence of ageing and attrition, total facial height was not found to differ significantly between the study sample and controls, and the smaller vertical incisor crown heights seen in the study sample were compensated for by apparent eruption of the lower incisor teeth and an apparent downwards displacement of the maxillary plane as measured n-sp and s-pm ($p<0.05$). An edge to edge incisor relationship was confirmed in the study sample, related to a longer mandible as measured pgn-cd ($p<0.001$), and greater values of mandibular prognathism (s-n-pg, $p<0.01$) when compared to controls. The facial profile soft tissue differences between control and sample categories demonstrated a flatter and longer upper lip, and more protusive lower lip and chin in the study sample. The study demonstrates a relationship between attrition and sagittal soft tissue morphology, and a relationship between ageing, attrition and vertical soft tissue relations.

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ACKNOWLEDGEMENTS

The investigation was carried out in the Department of Preventive Dentistry, University of Edinburgh and the clinical measurements were made in the Edinburgh Dental Hospital.

I am greatly indebted to Dr. Andrew Sandham, Department of Orthodontics, Edinburgh Dental Hospital for his guidance, support and constructive criticism throughout the period of the study.

I appreciate the co-operation of the departments of Conservative Dentistry and Dental Radiology, Edinburgh Dental Hospital for both the use of facilities and access to patients. I would especially like to thank Mrs. M.Phillips for carrying out all the radiography for the study.

My thanks are also due to the staff of the Department of Preventive Dentistry, University of Edinburgh for their encouragement during the investigation. I particularly express my appreciation towards Miss B.Wohlgemuth, Computing Support Officer for her invaluable advice and assistance with the computing and statistical calculations.

The illustrative work was carried out by Mr. D.Hunter, Technical Officer, Department of Preventive Dentistry and the typing was carried out by Miss C.Thompson to whom I also express my appreciation.

Finally, I wish to thank the patients who agreed to participate in the study and all my colleagues at the Edinburgh Dental Hospital who provided encouragement through the period of study.

DECLARATION

This thesis is the original work of the author with the exception of the help and guidance acknowledged in the text.

Andrew J.R.Crothers

GLOSSARY OF EQUIPMENT USED

a) **Radiography**

i) Cephalometric Radiography Machine

Siemens Orthoceph 5
Panelipse with Cephalometric Attachment
Seimens PLC
Seimens House
Sunbury on Thames TW16 7HS

ii) Cassette

Trimatic C Cassette 24x30cm
Trimax Y16 Calcium Tungstate Screen
3M Company PLC
Scotland

iii) Radiographic film

Kodak X-omat S 24x30cm
Kodak Limited
England

b) **Computer**

i) IBM PC/XT Model 256
IBM UK
P.O.Box 41
Portsmouth
England

ii) Monitor
IBM Personal Computer Display
Model 5151
IBM UK

c) **Digitiser**

Digipad 5
GTCO Coporation
Rockville
USA

d) **Printer**

Epson Printer LQ800
Seiko Epson Corporation
Japan

e) **Plotter**

Hewlett-Packard
7475A
Hewlett-Packard Co.
London

f) **Software**

Digiplot Software
University of Edinburgh
Department of Preventive Dentistry
High School Yards
Edinburgh EH1 1LZ

g) **Lightbox**

H.A.West Co.
Watson Crescent
Edinburgh

CHAPTER 1

INTRODUCTION

Dental attrition is found as a physiological change within the ageing dentition, occurring with varying degrees of severity, and involving loss of both occlusal and interproximal tooth substance (Begg 1954). It is seen in its most severe form primarily in primitive cultures or archeological specimens, where it is regarded as a routine finding with a well documented aetiology (Molnar 1983). Some workers have associated such severe tooth wear with a decreased incidence of dental disease, pointing out that the unworn dentition may be a pathological state found with modern diets (Newman 1974, Ainamo 1972, Berry, Poole 1974). In civilised societies severe dental attrition is regarded as abnormal but involves mainly occlusal rather than interproximal wear patterns (Russell 1987).

Various methods for assessment using indices for hard tissue loss and regimes for management of subjects with dental attrition have been described (Tallgren 1957, Eccles 1982, Smith, Knight 1984a,b, Olio et al 1987, Williams 1987, Brown 1980) but little work has been carried out on craniofacial changes that accompany this ageing process.

Loss of teeth and tooth substances appears to have an effect on facial height (sp-pg) (Tallgren 1957), and it has been suggested that compensatory mechanisms exist to allow for this loss of vertical dimension (Murphy 1959, Berry, Poole 1976). Attrition affects occlusion and temporo-mandibular joint function and morphology (Renson 1975, Granados 1979, Whittaker et al 1985) so it appears there is a more widespread craniofacial effect.

A previous study using cephalometric radiographs has shown that the average craniofacial morphology of subjects with advanced dental attrition differs from that of normal subjects (Krogstad & Dahl 1985). Similarly, previous studies using cephalometric radiography have demonstrated that growth changes in craniofacial morphology may continue throughout the third decade of life and beyond (Tallgren 1957, Forsberg 1979, Sarnas & Solow 1980), with only minor differences between the sexes.

The aim of the present investigation was to collect data for variables of hard and soft tissue craniofacial morphology in subjects with advanced dental attrition for comparison with a control group. The measurement error for the equipment used in the study was tested to enable reproducible values to be recorded for each set of measurements obtained. Data thus obtained for the control and sample categories were examined statistically to identify the differences that existed between the groups and any patterns of associations that were present within the control group and study sample.

CHAPTER 2

L I T E R A T U R E

A. INTRODUCTION

1) Definitions

i) Attrition

Dental attrition results in loss of tooth substance and can occur in a variety of ways. Klatsky (1939) defined this process as the gradual and regular loss of tooth structure caused by the natural process of mastication, and Murphy (1964) further pointed out that this loss of enamel and dentine occurs interproximally at the contact points as well as at the occlusal surface. Lewis and Smith (1973) similarly defined attrition as loss of tooth tissue due to wear between the contacting surfaces of the teeth. Renson (1975) attributed this wear pattern to the grinding of opposing teeth associated with mastication and unconscious habits, and Eccles (1982) suggested that attrition was a mechanism whereby tooth surface is removed by the movement of the teeth against one another, possibly with the influence of an intervening abrasive substance. Another similar definition, described by Shafer (1983), regarded attrition as the gradual and regular loss of dental tissue through tooth to tooth contact as a result of natural mastication. Soames and Southam (1985) also stated that this form of tooth wear could be defined as loss of tooth substance due to the result of tooth to tooth contact. Rowe and Johns (1986), in common with Murphy (1964), defined attrition as the gradual loss of incisal, occlusal and approximal tooth surfaces during mastication and Murray (1989) further developed this definition as the loss of hard tooth substance caused by mastication or contact between occluding or approximal surfaces.

Dental attrition may be both physiological and pathological, and its extent depends on a variety of factors. It may be that severe degrees of wear associated with an abrasive diet are within normal physiological limits (Murphy 1964, Berry & Poole 1974), and important for normal occlusal development. In a study of Aboriginal skulls (Begg 1954) severe attrition was a consistent finding throughout the dental arches, and this widespread wear could be considered as being non-pathological. Pindborg (1977) noted this, and suggested that the distinction between physiological and pathological attrition is that the former is generalised, while the latter is confined to single or groups of teeth, resulting from abnormal position or function. Gross or intensified attrition may occur as a third group, and this generalised pattern of tooth substance loss may, if sufficiently severe, impair function and lead to pathology (Williams 1987) (Fig.1).

The distinction between physiological and pathological wear must therefore depend on the aetiological factors involved, including the cultural environment in which the attrition occurs, and the presence of any other subsequent pathology (Russell 1987).

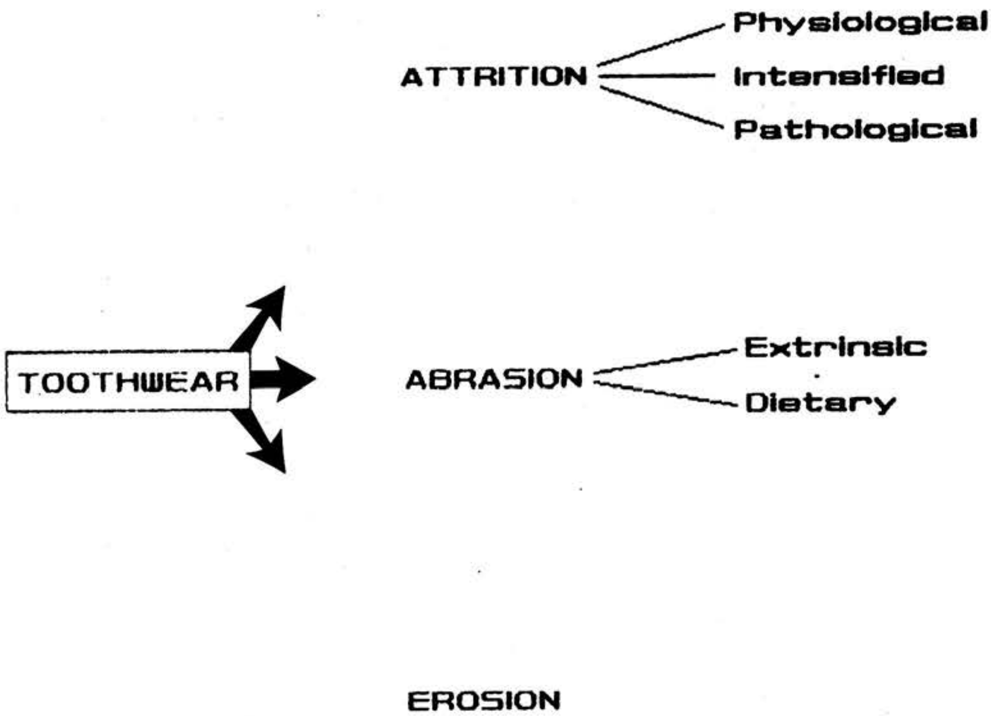
ii) Abrasion and erosion

There are three principal forms of tooth substance loss other than caused by dental caries. These are classified as attrition, abrasion and erosion. The definitions of attrition have been considered in the preceding section, and it is necessary to differentiate this form of tooth wear from abrasion and erosion.

Klatsky (1939) discussed this difference and stated that a definite line of demarcation existed between attrition and abrasion. Whereas the former could be attributed to mastication, both in terms of the muscular forces acting and the physical consistency of food, wear from abrasion was considered to be related to the introduction of extrinsic substances other than food in the mouth. Smith (1972) similarly separated the major components of tooth wear into distinct categories. Attritional loss of tooth substance was attributed to friction between opposing and adjacent teeth, and also to masticatory activities in which the consistency and abrasive quality of foodstuffs is a component of wear. In comparison, abrasion was defined as loss of tooth tissue due to the wearing effect of objects or materials other than food introduced into the mouth. Renson (1975) also defined abrasion as tooth wear associated with the friction caused by foreign bodies or substances (Fig.1).

FIGURE 1 Classification of toothwear

FIG. (1) CLASSIFICATION OF TOOTHWEAR



Another similar definition of abrasion is given by Eccles (1982) in which this process is described as the physical wear of tooth surfaces caused by agents introduced into the mouth. Turner and Missirlian (1984) however define abrasion as tooth wear due to the influence of external agents, including dietary factors. Best (1987) similarly regarded abrasion as tooth wear due to the mechanical action of dietary factors during chewing, or as a result of the introduction of external abrasive substances. This is similar to the definition of abrasion given by Johnson (1987) in which this form of tooth surface loss was regarded as being due to abnormal physical processes.

Erosion is defined as the loss of tooth tissue through the action of chemicals other than those produced by bacteria (Lewis & Smith 1973, Renson 1975). Eccles (1982) defines this process more simply by stating that erosion is the chemical dissolution of dental hard tissue in the absence of plaque.

Attrition, abrasion and erosion do not always occur independently. Often more than one of these processes is at work and it is often difficult to determine the part played by each form of tooth wear (Eccles 1982). Lewis and Smith (1973) discussed the association of erosion with attrition, and presented a series of case reports in which it was demonstrated that supervening attrition may mask an underlying erosive process. An earlier study by Ten Bruggen Cate (1968) also demonstrated increased rates of attritional tooth surface loss in an environment containing acidic fumes which produced dental erosion.

Attrition and abrasion may also occur together to produce a combined effect. For example, abrasion from foodstuffs may be considered to be a component of an attritional process (Smith 1972) or as being a distinct cause of abrasive wear (Turner & Missirlian 1984). However, abrasion often has a more distinctive aetiology, such as the inappropriate use of a toothbrush (Eccles 1982).

As often more than one cause of tooth wear may be present, (Eccles 1982) suggests that the term 'tooth surface loss' should be employed to describe the combined effects of attrition, abrasion and erosion in these cases. Williams (1987) supports this view and states that in many cases there is no interdependence of aetiological factors in advanced tooth wear.

2) Aetiological and Predisposing Factors

The aetiology of dental attrition and factors which may predispose a subject to this form of tooth wear are also reported in the literature.

The influence of dietary factors in the pathogenesis of this condition is considered by Begg (1954). An unrefined coarse diet which requires increased mastication will influence the rate of attrition, as will the inclusion of abrasive substances within the diet, present either due to the methods of preparation employed, or as a result of environmental factors (Roberts 1971, Molnar 1972).

Bruxism is defined as the frequent clenching and grinding of the teeth at times and for purposes other than the mastication of food. Tooth wear has been examined in the dentitions of known bruxists, and this parafunctional activity has been shown to have an association with increased amounts of attrition, and is thus an important factor in the pathogenesis of this form of tooth wear (Nadler 1968, Xhonga 1977). Colquitt (1987) also noted the association of accelerated tooth wear patterns with the sleeping postures of known nocturnal bruxists.

The habitual chewing of substances such as Betel-nut or tobacco has been reported as having an influence of the pathogenesis of attrition. Whilst substances such as these are not foodstuffs, they may be differentiated from the foreign bodies introduced into the mouth which may cause abrasion (Renson 1975).

Basker et al (1983) commented that attrition of the anterior teeth was a common consequence of prolonged unrestored lack of posterior support for the occlusion. Other workers have also agreed with this finding (Best 1987), the incisal amounts of anterior wear being due to increased function of the anterior teeth exceeding limits of physiological normality.

Many authors have stated that congenital abnormalities of the teeth such as amelogenesis imperfecta, dentinogenesis imperfecta or dental hard tissue hypoplasia of other aetiology may have an influence in increasing rates of attrition, either in the presence or absence of parafunctional activities (Hamilton & Whitehead 1968, Renson 1975, Turner & Missirlian 1984, Best 1987) due to the compromised quality of the existing tooth tissue.

The occupation of subjects showing marked attrition has also been implicated in the pathogenesis of tooth wear. Goldhaber and Goldberg (1954) presented a case report in which a severe case of occlusal wear was attributed to a combination of nocturnal bruxism and vibrational tooth contact resulting from the driving of an agricultural tractor. The authors did however note that any attempt to evaluate the relative importance of each aetiological factor would be merely speculative. Pollman (1987) also studied attrition in various groups of people including miners and truck drivers or machine operators, and associated these occupations with increased rates of attritional wear, again presumably due to vibrational tooth contacts.

The association of attrition with erosion has been reported by Lewis and Smith (1973). Five case reports were presented to illustrate that erosion is not uncommon, and is often overlooked due to supervening attrition. This was considered to be particularly important where the erosive and attritional processes occur simultaneously and the interdependence of predisposing and aetiological factors has been questioned by several researchers in this way. Eccles (1982) reviewed the aetiology of tooth surface loss and noted that in terms of diagnostic criteria, it is not always possible to differentiate between causal agencies, and often more than one aetiological factor is active. Smith and Knight (1984b) also compared patterns of tooth wear with aetiological factors. In this study of one hundred subjects showing marked tooth wear, despite extensive history taking and detailed clinical examination, only 69% of patients could be confidently allocated to one particular aetiological group. Of this percentage, 11% could be included in the attrition group, and another 16% apparently suffered from attrition occurring in combination with another causal factor.

Watson and Tulloch (1985) also commented on the difficulty of establishing the principle aetiological factor in cases of tooth surface loss. They stressed the importance of taking a detailed case history in these circumstances, and presented a classification based on the need for treatment to assist with this. Williams (1987) in discussing the association of attrition with erosion and abrasion, considered the aetiology of these forms of tooth wear, and proposed the hypothesis that there was in most cases no interdependence of these different causes of tooth substance loss.

3) **Anthropological and Archaeological Studies.**

Most early reports on attrition are based on observations and investigations obtained from archaeological specimens, or from studies of an anthropological nature made on primitive or aboriginal populations.

Some of the earliest examples of attrition are recorded from mummified remains excavated from archaeological sites in Egypt. Leigh (1935) examined such specimens, and noted that severe attritional tooth wear in all the teeth was a common finding, even in relatively young subjects.

Begg (1954) reviewed the dentition of Stone Age man and describes the attritioning of teeth as part of a dynamic process whereby the occlusion is developed and maintained throughout the life of an individual. The loss of tooth substance was attributed to a "natural" or unrefined diet requiring increased mastication, together with the presence of abrasive substances within foodstuffs due to environmental factors, or as a result of the methods of food preparation employed.

Attrition has been studied in many ancient populations, including Australian Aboriginal skulls (Begg 1954, Beyron 1964), medieval Swedish skulls (Lysell & Lennart 1958) and ancient American Indians (Fishman 1976).

Contemporary primitive societies have been reported on in detail by Dental Anthropologists (Campbell & Barrett 1953, Barnes 1969, Molnar 1972, 1983). In all cases severe attrition is a common finding where a natural unrefined diet is the norm. The presence of unrefined foodstuffs requiring increased mastication appears to be the common factor between both ancient and modern primitive groups. In studying these populations, the above workers report the contribution that these dietary influences make on the degree of attrition.

The aetiology and incidence of tooth wear has been examined with respect to various cultural influences (Leigh 1925, Roberts 1971, Molnar 1972). In particular, reference has been made to the effect of the inclusion of grit and sand in the diet, such as may occur in desert environments, or by the milling of cereals of flour on stone. Both of these factors have been shown to increase the quantity of abrasive substance in the food of people living in these conditions or employing these methods. The use of the teeth as tools is also quoted as possibly being a significant factor in the evolution of attrition in primitive societies.

Davies and Pederson (1955) examined the dentitions of Greenland Eskimos in both primitive and urbanised environments. As the social conditions became more civilised the degree of attrition found was observed to decrease. Though the primitive diet was not considered to be particularly abrasive, vigourous mastication was required in its consumption, which presumably led to an increased prevalence of tooth wear. The more modern diet required less mastication, and thus less attrition was observed in this group.

The above workers all regarded the influence of dietary factors as part of the attritional process, rather than as abrasive agents, as they produce their effect during mastication and tooth to tooth contact.

B ATTRITION AND DENTAL HEALTH

1) Effect on Occlusion.

i) Patterns of attrition.

Attrition may affect the dentition in a variety of patterns and may be defined as being both generalised and localised. Generalised or intensified attrition is most often seen in the dentitions of primitive or aboriginal populations and has already been considered in relation to archaeological and anthropological studies into this form of tooth wear (Begg 1954, Barnes 1969, Molnar 1972, Berry & Poole 1974, Fishman 1976).

Begg (1954) and Murphy (1959a, 1964, 1968) discussed generalised attrition in the dentitions of Australian Aborigines and recorded the details of the development of this process. The dynamics involved in the mastication of a natural diet were found to produce non-uniform wear in both interarch and intra-arch relationships. The attritional process initially produces increased wear on the first molars, with less attritioning stresses being effected on the second and third molars. As tooth wear progresses, differential wear patterns result in equivalent tooth surface loss being present on all molar teeth. Similarly the lower jaw was found to be initially subjected to increased attritioning stresses. The slope of the buccolingual plane of the occlusal surface of the first molar was observed to become reversed with increasing degrees of attrition, and wear of the anterior teeth was found to lead to the development of an edge to edge bite. The effect of attrition on the length of the buccal segment was also investigated by Murphy (1964). Contact points were demonstrated to become worn to highly polished flat or S-shaped contact areas, having the effect of reducing the mesiodistal dimensions of the teeth and thus resulting in an overall reduction in the length of the buccal segment.

Murphy (1968) also investigated the patterns of wear found on individual teeth in generalised attrition. Several stages in the reduction of tooth cusps were identified, and as with the pattern of wear throughout the occlusion, wear on individual teeth was observed to be non-uniform in nature, and associated with variations in the eruptive sequence and also with the reversal of the buccolingual plane of occlusion as noted by Begg (1954, 1977) (also termed the reversal of the Monson pitch). Differential degrees of wear on individual teeth were described in terms of faceting, dentine exposure, coalescence of facets and further coalescence of exposed dentinal areas with advancing wear. The patterns of wear found by Begg also suggest that in such generalised attrition, the anterior teeth take part early in function, leading eventually to an edge to edge incisor relationship. It has also been proposed that such generalised wear patterns may be within normal physiological limits for the primitive populations studied (Begg 1954, Berry & Poole 1974).

Generalised attrition is also noted as a feature of bruxism (Nadler 1968). Wear of the teeth due to this form of parafunctional activity has been observed to occur at faster rates than in non-bruxists, and may occur throughout the dentition as wear faceting or significant loss of occlusal anatomy in severe cases (Xhonga 1977).

Localised attrition has also been considered as a pattern of tooth wear. Pinborg (1977) defined this localised wear as that confined to a single tooth or groups of teeth, and regarded this as a pathological state. Eccles (1982) described localised attrition in the anterior segment as a common sequelae of loss of posterior support of the occlusion, or as a result of premature occlusal contacts such as may be caused by malpositioned or drifted teeth.

Turner and Missirlian (1984) also noted that extensive attrition of the anterior teeth often occurred as a result of loss of posterior teeth, malpositioning of teeth or occlusal interference resulting in a forward posturing of the mandible. Stern and Brayer (1975) also observed these findings and in addition proposed that loss of arch integrity, such as may be caused by loss of teeth, mesial drift or spacing, may cause premature occlusal contacts and the resulting adaptive change in horizontal jaw relationships may manifest as localised attrition in the anterior segment. Other factors which may place increased load on the anterior teeth, such as the provision of partial dentures lacking in posterior support may also produce similar localised attrition.

Isolated areas of attrition may also occur as a result of parafunctional activities such as nocturnal bruxism (Colquitt 1987) in addition to the generalised wear patterns noted above.

ii) **Attritional occlusion**

Studies on attrition in primitive and aboriginal societies form the basis on which theories regarding attrition and the development of tooth wear and its associated effects on oral health and facial morphology are founded. Whereas in modern cultures, the aetiological factors thought to be involved do not appear to be the same as those relating to anthropological studies (Smith & Knight 1984b), tooth wear may occur in similar patterns.

When advanced attrition affects the entire dentition, the changing occlusal relationships no longer relate to the accepted values of normal occlusion (Begg 1954). This has led to the concept of attritional occlusion, primarily described by Begg (1954, 1977). This theory proposes that all degrees of generalised attrition are physiological and that factors exist to compensate for the loss of tooth substance. The retention of the tooth cusps of the permanent dentition (whose function is claimed to be merely to guide the teeth into their correct occlusal relationships) has been regarded as being the persistence into adult life of a juvenile condition, and this may be associated with a general decline in the level of oral health (Klatsky 1939, Begg 1954, Ainamo 1972, Berry & Poole 1974). The development of this form of occlusion is carefully documented by

Murphy (1964, 1968), in which loss of tooth substance occlusally and interproximally is compensated for by the mesial and occlusal migration of the teeth. Attrition of this form allows for the formation of a wide occlusal table conducive with improved masticatory efficiency, and the reduction of tooth mesio-distal widths allows for the eruption of all teeth into arches without crowding in the deciduous, mixed and permanent dentitions. It has thus been suggested that retention of the post-eruptive occlusal morphology of the teeth is associated with a degenerative state in which crowding of the arches, and the retention of stagnation areas in the occlusal fissures and interproximal regions is encouraged (Murphy 1964, Ainamo 1972, Newman 1974).

Other workers have not supported the concept of attritional occlusion, and regard the severe degrees of tooth wear involved as pathological (Weinburger 1955, Smith 1972, Granados 1979). This is due to the apparently adverse effects that attrition may have on both the dental tissues and temperomandibular joint. Smith (1972) pointed out that the history of man's evolution pointed to the development of cultural methods of adaption to the environment rather than to the development of specialisations of the masticatory apparatus, such as the formation of an attritional state of occlusion. However the view has been put forward that the attritional state does improve masticatory efficiency (Russell 1982). The increase in occlusal surface areas caused by attrition, and the formation of sharp enamel edges surrounding smooth dentinal surfaces provides a better and more efficient means of shredding and grinding food, supporting the concept that severe attrition may be a natural physiological state (Begg 1954, 1977, Berry & Poole 1974).

2) Effects on Dental Health

i) Attrition and general oral health.

The significance of the unworn cusp in relation to the modern dentition has been noted in the preceding sections with reference to the concept of attritional occlusion. Observation and research has associated the features of severe attritional tooth wear with a decrease in the incidence of dental disease. Ainamo (1972) examined the relationship between occlusal wear and the periodontal health of the teeth. The occurrence and degree of attrition was recorded and associated with periodontal pathological conditions. Occlusal tooth substance loss was found to be associated with better hygiene standards and thus in most areas, with improved periodontal health. However, where major salivary glands open into the mouth, teeth showing attrition appeared to have increased amounts of calculus present, and thus no improvement in periodontal status could be observed in mandibular incisors and maxillary molars. It was concluded that the increased masticatory activity associated with attrition appears to decrease the accumulation of soft tooth deposits, and this was related to the observed better periodontal condition. These findings are in agreement with the views of Begg

(1977) who also noted that attrition reduced stagnation areas, particularly interproximally where contact points are reduced to broad contact areas. It is however accepted that the aetiology of periodontal disease is multifactorial (Manson 1980) and that an improvement in hygiene standards through attritional processes may be only one factor in the decreased incidence of periodontal disease in such subjects. Newman (1974) noted that the different diet textures found in populations showing attrition influenced their plaque biology, which may lead to a decreased incidence of periodontal problems in these subjects, as well as decreasing stagnation by allowing less plaque to accumulate.

The decreased incidence of dental caries in subjects with advanced attrition and in primitive populations showing attritional occlusion has also been observed (Leigh 1925, Begg 1954, Murphy 1964, 1968, Berry & Poole 1974, 1976). The obliteration of occlusal fissure patterns and the broadening of interproximal contact areas by attrition effectively ablates the potential stagnation sites normally associated with this disease. Dietary influences are however again important, as a natural diet is less likely to contain the refined carbohydrates that are also associated with caries, and thus a decreased caries incidence is likely to be related to more than an increase in oral hygiene standards brought about by an alteration of occlusal and interproximal tooth morphology through attrition.

It has also been proposed that the freedom of masticatory movements associated with a flat occlusal table would not be likely to be related to temperomandibular joint dysfunction or myofascial pain, and that lack of attrition may be conducive to the restricted masticatory movements which may have a role in the aetiology of these conditions. The finer muscular control needed to reach the intercuspal position may well overstrain muscles already weakened by hypofunction in a non-attritional state (Nadler 1968, Berry & Poole 1974, Ramfjord 1983).

The reduction in mesiodistal tooth dimensions by interproximal attrition may be a major factor in compensating for discrepancies between arch lengths and tooth sizes, and may therefore be important in the low incidence of malocclusion and crowding which may be observed in primitive societies, where attritional occlusion is a normal finding. This form of interproximal tooth wear may provide space for the eruption of all the teeth throughout the development of the dentition. Murphy (1964) described the reduction of the dental arch through interproximal attrition and demonstrated that approximal tooth wear proceeded rapidly in early life, corresponding with the eruptive phase of the teeth, and continued at a diminished rate through adulthood. The conclusion was reached that lack of interproximal wear denied space in the dental arch for eruption, and this may account for the increase in the incidence of crowding and malocclusion (and also third molar impaction) that may be observed in modern populations. Begg (1977) further considered these observations and suggested that the balance between tooth size and jaw length was only in equilibrium in the presence of interproximal attrition. Thus, mechanisms designed to compensate for this form of tooth wear become distorted in its absence, and the resultant effect produced impacted and malpositioned teeth, ill-formed arches, and therefore malocclusion.

It has therefore been proposed that the present state of unworn cusps in modern man, the lack of the dietary influences that produced attrition, together with the subsequent decrease in masticatory function is concomitant with a generalised decrease in the standard of oral health. Based on these observations, some authors have felt justified in proposing the progressive reduction of tooth cusps and interproximal stripping as a general prophylactic measure (Murphy 1964, Berry & Poole 1974, Begg 1977).

The incidence of severe generalised attrition is rare in modern populations (Carlsson et al, 1985) and attritional states in this group are generally related to more aetiological factors than diet alone (Smith & Knight 1984b, Johnson et al 1987). This form of tooth wear is, however, likely to become of increasing importance in the context of the ageing dention. As preventive dentistry is more widely and successfully practised, so teeth are more likely to be retained for a greater proportion of an individuals life, and thereby subjected to a greater degree to those factors which may produce tooth wear (Eccles 1982). These include environmental and dietary factors, and conditions which are often found in the ageing dentition such as lack of posterior support, occlusal collapse and parafunctional activities (Nadler 1968, Renson 1975, Russell 1987).

ii) Effect of attrition on individual teeth

The effects of attrition on individual teeth is reported in the literature, both in terms of the patterns of wear seen, and the associated effects on the dental tissues.

Murphy (1968) described seven stages in the development of occlusal wear. Initially, faceting is observed in the enamel, and as attrition progresses, worn areas coalesce and dentine becomes exposed. Cuspal height is progressively reduced and occusal fissure patterns become obliterated. Exposed dentinal areas enlarge and coalesce as wear continues, leading to the formation of depressed dentinal areas surrounded by raised rims of sharp enamel (Berry & Poole 1974). Begg (1977) also reports similar observations and notes that as attrition progresses, the teeth erupt (also Murphy 1959b) and eventually the crown of the tooth may become completely destroyed by the wear process. If this occurs, spacing between the teeth may develop due to their greatly reduced vertical and mesiodistal dimensions. Exposure of the pulp during the development of this severe wear is prevented by the continual deposition of irregular secondary dentine within the pulp chamber and root canal. This feature is a characteristic response to progressive attrition in teeth (Cawson 1984). Tronstad and Langland (1971) evaluated histologically the pulpal reaction to attrition in a variety of species, including humans. The most characteristic response to this stimulus was the formation of localised areas of irregular secondary dentine. The tissue of the pulp was found to show mild inflammatory changes, and a tendency towards fibrous replacement. This response to attrition was however found to vary between species in this study, and it was concluded that the process of secondary dentine formation did not entirely protect the pulpal tissue from attrition. Haughen (1975) also evaluated the frequency and extent of the pulpal reaction to attrition in a study was performed on monkeys, and as before, the response to this form of tooth wear was the formation of secondary (reparative) dentine. Pulpal tissue adjacent to this secondary dentine showed normal histological features, with a low incidence of inflammatory changes. This is in agreement with the work of Tronstad and Langland (1971) who also noted a low incidence of inflammation in monkey teeth with attrition. The results in this earlier study would, however, indicate that these findings may not be applicable to the human dentition, as more complex inflammatory changes were seen in human deciduous and permanent teeth.

Exposure of the pulp may occur through attrition, particularly where the rate of wear is faster than may be compensated for by secondary dentine formation (Russell 1987). Evidence of such pulpal trauma was observed by Leigh (1925, 1935) in primitive populations, and though abrasion was also implicated in its pathogenesis, the dentitions of the subjects all showed generalised attrition. Klatsky (1939) stated that pulp exposure was an inevitable consequence of advanced attrition, though Begg (1977) states that the pain of near exposure would cause avoidance of the affected tooth and allow the reparative secondary dentine to be laid down. In modern populations where attrition is rapid or localised, pulpal exposure may occur as a feature of advanced wear (Renson 1975, Smith & Knight 1984a). Prior to this, irritation and discomfort for the patient is normally caused by soft tissue trauma from sharp edges of enamel produced by the coalescence of wear facets, or from dentine hypersensitivity as progressively larger amounts of dentine become exposed (Johnson et al 1987, Gankerseer 1987). Once the stage of pulpal exposure is reached, pulp death is inevitable, though it is reported that sterile necrosis of the pulp has been observed to occur painlessly prior to frank exposure through attrition (Russell 1987).

The effect of attrition on the dental hard tissues was also noted by Xhonga (1977). In both enamel and dentine, well pronounced grooves and striations at a microscopic level are present, and fracturing or crushing of enamel prisms is also seen. It was proposed that enamel crystals in a pulverised form may damage the surface further, at a rate determined by the pressure and speed of tooth to tooth contacts.

3) Physiological and Pathological Attrition.

Whereas some workers regard attrition as a normal finding in all its degrees of severity (Begg 1977), many others have made a distinction between this proposed physiological process and a pathological condition, and indeed there is considerable controversy on this subject.

Klatsky (1939) regarded attrition as a physiological state associated with natural mastication. Fishman (1976) regarded it similarly as a condition associated with a more efficient masticatory apparatus, the lack of which encouraged dental disease in modern man. This view was supported by Murphy (1964) who proposed that the lack of approximal attrition in civilised man was an important cause of malocclusion, occlusal disharmony and impaction of the lower third molar tooth. Aimamo (1972) studied the relationship between attrition and periodontal health and indicated that there was circumstantial evidence that this form of tooth wear may represent an important and often indispensible occurrence in the development and maintenance of a properly functioning masticatory organ. In a study of army recruits, occlusal wear was found to be associated with improved cleanliness and thus also with improved periodontal conditions.

This idea was supported by Berry and Poole (1974) in a report in which they compared the human dentition to other animal dentitions in which attrition is necessary to achieve full masticatory efficiency. They suggested that from their observations, in animals where the function of the dentition is mastication rather than prehension, tooth wear is normal and indeed necessary to attain full efficiency. A similar characteristic was found in man, in societies that existed on a primitive diet, and on the basis of these observations, the authors proposed that the prophylactic grinding of tooth cusps was a justifiable procedure.

Contrary to these ideas, not all researchers have viewed attrition as a natural process. Klatsky (1939) whilst regarding attrition as a normal process, did acknowledge that it became pathological when sufficient tooth substance loss occurred and exposure of the pulp resulted. Weinburger (1955) took exception to the view that any attrition was natural and that tooth contacts during the masticatory cycle should not provide sufficient force to produce such wear. Elfenbaum (1967) noted that the widened occlusal tables present in attritional states may overload the teeth and advocated their reduction to restore the original masticatory force that these teeth should deploy. He also suggested that the restoration of some form of occlusal anatomy was necessary to permit effective chewing. Smith (1972) in a review of studies in tooth wear also stated that attrition was an undoubtedly harmful process, whereas Wise (1977) commented that is was an uncertain concept as to how much tooth wear is acceptable in modern man.

Pindborg (1977) defined pathological attrition as being confined to single teeth or groups of teeth, caused by their abnormal function or position. He regarded the gradual and regular loss of tooth substance through mastication as physiological, and further described a variation of this group in which the wear rate was accelerated. This subdivision was termed 'intensified attrition'. Filipowicz (1978) considered occlusal wear to be physiological unless the clinical crown was destroyed, or the vertical dimension of occlusion was altered such that temperomandibular joint symptoms were elicited. Granados (1979) however, disagreed with the views of Begg, Fishman and Murphy, as a study conducted by him associated severe attrition with osteoarthritic changes in the bony elements of the temperomandibular joint complex.

Turner and Missirlian (1984) referred to minimal and gradual attrition as a natural process, but stated that excessive wear could cause occlusal disharmony, impaired function and aesthetic disfigurement. Similarly, Smith and Knight (1984) commented that tooth wear could be regarded as pathological if the tooth became so worn that it was unable to function effectively, or if appearance was compromised.

Russell (1987) in a review of the above literature made his own observations regarding the distinction between physiological and pathological attrition. He concluded that classification of occlusal wear through attrition as being physiological and normal, or pathological and therefore abnormal, must be seen in the context of the cultural environment and the circumstances under which it has occurred. If attrition renders a tooth vulnerable to functional loading, then this must be regarded as abnormal. Similarly, if occlusal wear has occurred at a rate faster than can be compensated for by physiological mechanisms, this must also be pathological. These conditions were considered to apply to both the conditions of generalised and localised attrition. In addition Russell also noted that compromised aesthetics by our standards may not be regarded as abnormal in other cultures, and therefore the patients attitude to the situation must be important in deciding whether or not the wear experienced should be regarded as pathological and in need of treatment.

C CRANIOFACIAL CHANGES

1) Dentoalveolar and craniofacial effects of attrition.

There are many reports in the literature on the possible compensatory mechanisms that may occur in response to the loss of tooth substance that occurs as a result of attrition. There are also a number of reports of a subjective nature on the apparent changes that occur in the vertical dimension of occlusion due to advanced tooth wear. There are however, relatively few reports that attempt to evaluate and quantify such dentofacial changes. The research in the literature relevant to such changes is considered below.

i) Interarch relationships.

Changes in interarch relationships have been noted due to attrition. Fishman (1976) in a study carried out on American Indian archaeological specimens noted a general decrease in arch dimensions with increasing degrees of attrition. Midsagittal arch length was found to decrease more in the mandible than in the the maxilla. In both intercuspid and intermolar arch widths the decrease was found to be twice that of the maxilla in the mandible. This result does not however concur with earlier work by Murphy (1964) who noted a general increase in maxillary intermolar arch width with advancing degress of attrition. This finding is in agreement with the results of Begg (1977) in a study carried out on skulls taken from a population of Stone Age man. He, in common with Murphy, noted an increase in maxillary intermolar arch width, and a decrease in mandibular intermolar arch width. Begg associated this change in dimension with a reversal in the bucco-lingual plane of occlusion, from a cant downwards buccally to lingually, to a cant downwards lingually to buccally, with increasing degrees of attrition. This reversal of the Monson pitch was attributed to differential wear of the palatal cusps of the upper teeth and buccal cusps of the lower teeth, an observation agreed with by Murphy (1968). The net result of this change was to alter the forces acting on the upper and lower jaws, such that the upper molars were forced buccally, (thus widening the upper arch) and the lower molars were forced lingually (thus narrowing the lower arch). This also had the effect of bringing the cusp of Carabelli into occlusal function, and thereby increasing the area of the occlusal table. This reversal of the bucco-lingual plane of occlusion was a feature also noted by Fishman (1976), though as previously noted, an increase in the maxillary intermolar arch width was not reported.

Murphy (1968), Fishman (1976) and Begg (1977) also noted the development of an alteration in incisor relationships with increasing attrition. The plane of occlusion sloping downward and labially in a non-attritional state, became more horizontal as the severity of wear increase. This led to the reduction of the incisor overbite, though this did not necessarily lead to the development of an edge to edge incisor relationship. This may however, develop as the mandible is postured forward, the occlusion being unlocked more posteriorly through the progressive ablation of tooth cusps.

The above workers have also observed the reduction in arch length through attritional processes. This was investigated in detail by Murphy (1964) who found that each buccal segment was reduced by approximately 8-10% of its original length (approximately 7mm for each arch). Begg's figures however, suggest a slighly greater reduction in arch length, of the order of approximately 10mm per arch. This is also of the order of the data obtained by Fishman (1976).

ii) Effects on the vertical dimension of occlusion, interocclusal clearance and facial height.

Considerable attention has been placed in the literature on the apparent effect of attritional processes on the vertical dimension of occlusion or morphological face height, and possible effects on the interocclusal clearance. The assessment of possible decreases in facial height through attrition are often based on arbitrary clinical grounds, and there is considerable controversy as to the importance of such findings. Some authors, in presenting case reports describing various treatment rationales for the management of advanced attrition, have noted clinically an apparent reduction in the vertical dimension of occlusion, a features often described as "overclosure" (Mack et al 1968, Hamilton & Whitehead 1968, Gankerseer 1987, Best 1987). Other workers have commented on this apparent effect in greater detail. Tallgren (1957) studied the changes in adult face height that occurred due to ageing, wear and loss of teeth and prosthetic treatment. The section of this study that was concerned with the effects of tooth wear revealed several important considerations. The wear considered here was mainly loss of occlusal tooth substance as the subjects were of a contemporary population which lacked the diet required to produce significant interproximal wear patterns. The aetiological factors were not taken into consideration in this study. The morphological face height in these subjects showing attrition was found to be extremely reduced when compared to corresponding age matched control groups. A tendency for the resting facial height to be reduced was also noted, though due to the small number of subjects in the sample, statistical confirmation was not obtained. The interocclusal clearance was found to be increased in the sample, and it was thus concluded that advanced attrition reduced the morphological face height, and the resting face height adapted only partially, thus creating the observed increased interocclusal clearance.

Murphy (1968) also described a reduction in occlusal facial height associated with increasing degrees of attrition in a population derived from Australian Aboriginal skulls. Bojanov et al (1968) described an anthropometric system of measurement by which this reduction in facial height through attrition could be measured. No figures were given in this report to illustrate by how much this dimension could be reduced. Similarly Renson (1975) commented that advanced attrition particularly that caused by lack of posterior support for the occlusion, was often associated with overclosure, and subsequent temperomandibular joint dysfunction.

Dahl et al (1975) observed the effects on the vertical dimensions of the face in the treatment of a patient suffering from advanced localised anterior attrition. They commented that clinically, a reduction in the morphlogical facial height is commonly observed in such cases and that restoration of this dimension is widely accepted as part of treatment. Bearing in mind the results of their research, and the earlier work of Tallgren (1957), the authors concluded that it seemed reasonable to assume that a small increase in morphological face height to facilitate the placement of restorations could be tolerated by the patient.

Brown (1980) accepted that loss of the vertical dimension of the lower face was inevitable in cases of advanced tooth wear, and advocated the restoration of this dimension to its original height as assessed by the reduction in the length of the teeth. A temporary appliance was suggested to test the patient's tolerance of this restored dimension. Turner and Missirlian (1984) also noted that it was commonly assumed that extensive occlusal wear resulted in decreased occlusal vertical dimension. It was commented that rehabilitation to an increased height may result in post-operative complications. For this reason, it was considered essential to evaluate and verify such loss of vertical height, prior to embarking on complex restorative procedures. Watson and Tulloch (1985) also observed that clinical overclosure with a reduction in interocclusal clearance is commonly found in attritional states. This is in contradiction with the observations of Tallgren (1957), though the authors did accept that cases existed where the interocclusal distance appeared to be increased. Again, the use of a diagnostic appliance was advocated to assess the degree of overclosure and to determine to what extent the patient may cope with an increase in facial height.

Devlin (1985) noted that loss of vertical dimension does not inevitably result from tooth wear. It was proposed that careful measurement of the interocclusal clearance may determine whether or not some form of compensation has occurred. It was also pointed out that restorations placed within an increased interocclusal clearance may result in problems of adaption for the patient. Once again, the use of an intermediate appliance was advocated.

Russell (1987) reviewed the previous literature and concluded that a decrease in the morphological and resting face height occurred with attrition, and that an increased interocclusal distance was often associated with this. In commenting on Tallgren's results, Russell observed that they should be interpreted with caution, as often subjects exhibiting marked attrition had lost posterior support with resultant collapse of the occlusion, an effect which may in itself contribute to the measurements obtained, rather than as an effect of the attritional processes alone.

To investigate further these apparent changes in facial morphology associated with alterations in the vertical dimension of occlusion, Dahl and Krogstad (1975, 1982, 1985) instigated a longitudinal survey of the effects on the morphological face height of treatment in cases of localised anterior attrition. The treatment was carried out by a combination of orthodontic and prosthetic means. In this technique of treatment, a generalised alteration of the vertical dimension of occlusion was achieved by means of an anterior cobalt-chromium splint, which provided space for the provision of restorations after a period of wear. Whether or not this space was achieved by intrusion of the anterior teeth, or by allowing the eruption of the posterior teeth, was considered a controversial issue.

In this study, the effect on the morphological face height was studied using cephalometric radiography after the insertion of Tantallum implants, using the method originally described by Bjork (1968). The results obtained indicated that after 8 months of wear of the appliance, almost 2mm of increase of anterior face height had been achieved. Restorations were subsequently placed within this increased vertical dimension. Follow up studies of this report confirmed that such an increase in facial height was well tolerated, and a long term review confirmed the stability of the new increased vertical dimension. Though some relapse was found to occur, in no case did the dimension return to baseline measurements. Krogstad and Dahl (1987) subsequently repeated this line of research by investigating the relationship of the intrusive effect of such a bite splint when used in the treatment of severe attrition. It was originally suggested that the degree of intrusion of the anterior teeth may vary with the horizontal angles of the face but the results of the study did not reveal such a relationship.

The vertical dimension of occlusion has also been shown to be subject to alterations as part of the normal ageing process. Tallgren (1957) in a study which included normal material, showed that continued growth of the morphological face height occurred throughout the whole of adult life. A similar change in the resting facial height was also noted, indicating a synchronous development of these dimensions. This result was said to suggest that growth of the face was accompanied by a corresponding functional adaption of the associated neuromuscular system to maintain a constant interocclusal distance. This finding is supported by the later work of Thomson and Kendrick (1964) who also studied the changes in vertical dimensions of the face in later adult life.

This apparent increase in lower facial height with advancing age is considered further by other workers when investigating the possible mechanisms that may exist to compensate for the loss of vertical dimension that accompanies attritional processes.

ii) Attrition and craniofacial morphology

Whilst much attention has been focused in the literature on the effects of attrition and its treatment on the vertical dimensions of the face, little research has been carried out on the more widespread influences that this may have on craniofacial morphology.

Galabert (1975) conducted a cephalometric survey of medieval skulls with attrition and compared them with modern populations. The craniofacial relations and interarch relationships were noted in 29 archaeological specimens, and linear and angular measurements of facial profile were noted. No quantitative assessments of any observed differences were reported in the publication, though the author stated that such differences existed, and that further research on this subject would be useful.

Fishman (1976) conducted a similar survey of the dental and skeletal relationships to attritional occlusion. In this study, the skulls of American Indians were investigated, and the work in the literature has previously been quoted with respect to the incidence, prevalence and aetiology of attrition in such primitive populations. Subjects were separated into four groups showing increasing degrees of attrition. Linear and angular variables of craniofacial morphology were studied using standardised lateral cephalometric radiographs. Study model casts obtained from the specimens were also analysed for differences in arch configuration and variations in tooth sizes and arch length. The results suggested that with increasing attrition, the following changes in the lower facial skeleton and dental relationships occurred.

1. There appeared to be a forward positioning of the upper incisors as attrition progressed.
2. The gonial angle decreased as the degree of attrition became more severe. This occurred without any significant change in lower incisor inclination to the mandibular plane.
3. The interincisal angle increased as the degrees of attrition increased. This was attributed to the decrease in the gonial angle rather than to an uprighting of the incisors.
4. The incisors and first molars appeared to be repositioned more superiorly within the lower facial complex.
5. No change was observed in the cant of the occlusal plane.
6. The first molars were found to have moved anteriorly as attrition progressed.

From the study model casts, the following changes in arch form and dimensions were noted:

1. Arch width and length were found to decrease with advancing attrition.
2. The interpremolar width was found to decrease more than the intermolar width.
3. In both interpremolar and intermolar arch widths, the percentage decrease in size of the mandible was twice that of the maxilla.
4. The mandibular decrease in midsagittal arch length approximated four times the magnitude of the maxillary decrease with advancing attrition.
5. There was a consistent reduction in tooth size as attrition progressed. This was noted to often lead to anterior spacing.

A general analysis of the occlusion revealed that in 81% of subjects showing class I molar relationships, the molar relation did not change despite the absence of an overbite due to incisal wear, and also despite the anterior repositioning of the teeth.

Fishman thus concluded that the effects of attrition were not limited to the reduction of individual tooth dimensions. Maxillary and mandibular molars drifted anteriorly, maxillary anterior teeth demonstrated a similar effect, though the mandibular incisors appeard to be more stable. An increase in lower incisor proclination and uprighting of the upper incisors was not seen, as reported subsequently by Begg (1977). The intra-arch widths also decreased with increasing attrition, again partly in contradiction with the observations of Begg, who noted a decrease in mandibular width only, and an increase in the maxillary arch width. As occlusal and interproximal attrition progressed, the occlusal plane was seen to move vertically within the lower facial complex. Concomitant with this, the mandibular gonial angle and lower facial height decreased. Fishman concluded his research by stating that further investigation into these observed changes was required.

Krogstad and Dahl (1985) conducted a study based on similar principles in 20 adult individuals of Norwegian ancestory. These subjects, all suffering from advanced attrition in the incisor region had dento-alveolar and basal measurements recorded using standardised lateral cephalometric radiographs obtained according to the methods of Bjork and Solow (1962). The following points were noted from their investigations on comparison of the study data with a control group:

1. No special traits regarding the cranial base angle were noted in the study sample, though a general analysis of other basal angular dimensions revealed a slight tendency towards smaller values of the angle of relative prognathism when compared to previously recorded values from normal material.
2. The vertical dimension of the upper face was comparable to normal values, but the corresponding value of the angle representing the total facial height (Nasion-Sella line/Mandibular plane angle) revealed smaller values of lower facial height (a difference of approximately 8°)
3. The inclincation of the mandibular base line to the mandibular plane was within normal limits.
4. The gonial angle was less by approximately 10°, indicating a more strongly developed gonial process.

5. Linear measurement of lower facial height was smaller in the study sample.
6. The inclination of the upper incisors to the Nasion-Sella line was lessand the inclination of the lower incisors to the mandibular plane greater. The interincisal angle was similarly greater in the sample. This is in accordance with the observations of Begg (1977) but contrary to those of Fishman (1976) and Varrela (1990).

In the discussion in this report, the authors noted that dietary factors had little importance in the attritional processes seen in this contemporary sample and viewed the results obtained as circumstantial evidence that the attrition observed was due to increased masticatory function, and that the more developed musculature associated with this had influenced the skeletal morphology. It was also noted that the workers reviewed had reported uprighting of the upper incisors associated with an edge to edge bite. However in this study, most of the subjects possessed horizontal overjets, and this finding in these circumstances was tentatively ascribed to circumoral muscle forces.

Varrela (1990) conducted a study in which an anthropological sample of 15th century Finnish skulls was analysed cephalometrically for comparison with present day Finnish subjects. Severe attrition was prevalent throughout the anthropological sample whereas the dentitions of the normal material were virtually unworn.

The gonial angle and maxillary/mandibular plane angle were significantly smaller in the study sample and the upper incisors found to be more inclined toward the maxillary plane. Cranial base structures were similar in both groups. The author stated the results demonstrated that intensive mastication affected mandibular growth by advancing its anterior rotation and suggested that lack of this mastication promoted a more posteriorly directed growth. The results of this study are in general agreement with those previously reported, though again no reference was made to the validity of comparing ancient and modern populations.

iv) Attrition and temporomandibular joint changes.

In considering craniofacial morphology in subjects with severe attrition, some researchers have investigated possible alterations in temporomandibular joint morphology.

Murphy (1958) whilst studying mandibular morphology in Australian Aboriginal skulls observed alterations in this respect. He noted that when attritional tooth surface loss results in decreased interocclusal clearance, alterations in skeletal relationships occur at the temporomandibular joint. In this region, adjustment to functional attrition was said to be made by condylar growth. Other changes in mandibular morphology involved reduction in ramus width and deepening of the mandibular notch. How these changes in ramus form could be considered adaptive was proposed to be ill-understood.

Granados (1979) studied the influence of loss of teeth and attrition on the morphology of the articular eminence. Contemporary skulls belonging to different racial groups, and prehistoric American

Indian skulls were investigated. The results obtained indicated that the dentition was a significant factor in determining the angulation of the articular eminence. Attrition was found to modify the eminence so as to reduce the angulation in adult individuals. The changes observed were found to be similar to those seen in osteoarthritic diseases of the joint.

Whittaker et al (1985) also investigated the relationship between attrition and the temporomandibular joint changes. A population of 204 Romano-British archaeological specimens were studied. Unlike the previous study, in this case it was not posssible to show a significant positive correlation between attrition and remodelling changes in the temporomandibular joint. The authors considered this result surprising, as such correlations are shown in other research (Richards & Brown 1981). It was however noted that the degree of attrition in this population though marked, was not severe, and this factor may account for the lack of positive correlation in this investigation.

Williams (1987) reviewed the possible changes in temporomandibular joint morphology that could be associated with alterations in functional demand, and concluded that the joint complex could only adapt within certain limits, after which osteoarthritic changes would occur.

2) Compensatory Mechanisms in Attrition

The effects of attrition on tooth morphology, arch forms and skeletal relationships are well documented in literature and are reviewed above. To further explain these effects, some authorities have proposed mechanisms by which attritional tooth substance loss may be compensated for, and the significance of the observed skeletal changes with respect to this compensation have been discussed.

Murphy (1959b) discussed these compensatory mechanisms to functional tooth attrition. The earlier opinions of Begg (1954) and Tallgren (1957) were considered. Murphy observed that an investigation into possible compensation for loss of vertical face height through attrition was required, and presented such a study to evaluate the effects of the wear on this dimension. The study was carried out on Australian Aboriginal skulls, separated into two groups, showing moderate and advanced attrition. The loss of crown height was used to estimate the original vertical dimension as it would have been in the original non-attritional state. As enamel is not subject to further growth or resorbtion, it was considered appropriate to use the loss of crown length as a measurement of loss of vertical dimension, and comparison of this value with the actual recorded face height would indicate whether or not any skeletal compensation occurred. Observations made on the sample indicated that attrition was accompanied by a loss of total facial height. The upper facial height appeared to be unaffected, with the loss of vertical dimension occurring in the lower face. Loss of interalveolar height occurred to a greater degree than the loss of lower facial height. It was also observed that there was a small gain in maxillary and mandibular heights, and an overall decrease in tooth socket depth. From analysis of these observations and the measurements recorded, Murphy concluded that for the degree of attrition described, continuous tooth eruption compensated for approximately 50%. Of this mechanism of compensation, about two thirds was accounted for by differential alveolar bone deposition with socket shallowing, and one third by cemental apposition and subsequent root lengthening. Additional compensation by general alveolar bone deposition was also proposed. This left an uncompensated loss of facial height of approximately 40%.

Murphy commented that other workers had found an increase in lower facial height with increasing age (Hrdlicka 1936, Tallgren 1957), and suggested that the compensatory factors may continue in the absence of attrition, accounting for the observed increase in lower vertical facial dimensions. Berry & Poole (1976) also considered possible mechanisms of compensation for attrition. In a previous paper (Berry & Poole 1974) the authors had proposed a theory that the unworn cusp was a disease of civilisation, and that attrition was a necessary process to achieve full masticatory efficiency. They further considered the proposals of Murphy (1959b) and discussed three possible situations. Firstly, where attrition was rapid, alveolar bone growth did not adequately compensate, and the occluding face height would decrease. In this case it was assumed that the mandibular rest position remained constant, and thus the interocclusal distance increased. Secondly, the authors considered the situation where attrition was slower in developing, and alveolar bone growth was able to compensate for the reduction in tooth length. The third situation discussed was that when no attrition was present, skeletal compensatory factors continued with a resultant increase in lower facial height. The validity of the assumption that the resting mandibular position remained constant was then examined, and it was concluded that this supposition was unjustified. This conclusion is supported by evidence and observations provided by other workers who have indicated that the interocclusal space and rest position of the mandible remain relative to the occlusal vertical dimension (Tallgren 1957, Turner & Missirlian 1984).

Evidence indicates that the human face becomes longer with age (Hrdlicka 1936, Lasker 1953, Baer 1956). Berry and Poole concluded that it seemed reasonable to assume that alveolar growth did continue in the absence of attrition to provide this observed lengthening of the face. The fact that this increase in lower facial height has only been observed in the last two hundred years was considered significant, as it corresponds to the refinement of the modern soft diet.

The compensatory effects of the mesial and occlusal migration of the teeth are also reported in the literature. Loss of tooth height and mesio-distal length through attrition is compensated for by these movements of the teeth as attrition progresses (Begg 1977, Wise 1977, Turner & Missirlian 1984).

Despite the evidence reported above, there is however some controversy as to whether loss of tooth length necessarily results in a decreased vertical dimension of occlusion. (Devlin 1985, Johnson et al 1987). It is generally considered that whether or not such a change occurs is related to the rate at which the attritional process progresses, and to what degree the physiological compensatory mechanisms can operate in response (Russell 1987).

The compensatory mechanisms which operate in individual teeth are also considered. The main response to attrition is the formation of secondary dentine to prevent exposure of the pulpal tissue (Haugen 1975). Begg (1977) regarded the stimulation of pulpal pain through near exposure as a compensatory mechanism, as it discouraged function at the affected site and encouraged the formation of alternate patterns of mastication, the net result being reduced wear on the affected tooth, allowing the reparative process of secondary dentine formation to continue.

3) Effects of Ageing on the Adult Craniofacial Skeleton.

There are many reports in the literature indicating that growth of the facial skeleton continues into and beyond the third decade of life, after the major growth period is complete. Hrdlicka (1936) reported on the changes in both stature and facial height that could be observed with advancing age in adult American Indians. Stature was found to increase generally until around the fourth decade, whereas total facial height was observed to increase at a relatively faster rate, and also to continue up to the fifth and sixth decades. Lasker (1953) studied the effects of ageing on bodily measurements in adult male and female Mexicans. An increase in facial height was again noted throughout the first part of adult life, also continuing into the fifth and sixth decades, after which the loss of teeth that occurred could be associated with a decrease in the vertical dimension of the lower face. Baer (1956) similarly showed an increase in vertical facial height in the third decade of life. No changes in head length, breadth or circumference could be associated with this increase.

Tallgren (1957) investigated the changes in adult face height due to ageing, wear and loss of teeth, and prosthetic treatment. In this report, the effects of ageing were studied on subjects with normal intact dentitions. A significant increase in facial height was noted between groups of subjects aged 20-29 and 50-81. No significant change in the interocclusal distance was observed between these groups. The conclusion was reached that growth of the morphological facial height continues throughout the adult period, and that the lack of change in the interocclusal clearance suggests that the resting face height also increases through adaption of the associated neuromuscular systems.

Thomson and Kendrick (1964) conducted a cephalometric radiographic appraisal of vertical skull growth in male subjects aged 22-34 years over the period of one year for each subject. A significant increase was noted in all dimensions of the skull, with the exception of anterior cranial height over this span of time. Upper facial height showed a small increase, with a much larger increase being present in the vertical dimension of the lower face. The authors thus demonstrated that vertical growth of the face does continue in the early adult period, though no longitudinal assessment of this was made.

Murphy (1968) reviewed the work of the above authors and suggested that this observed increase in facial height could be associated with a decreased incidence of attrition. The increase in this dimension was proposed to have been brought about by skeletal growth and continual tooth eruption which would normally act as compensating mechanisms for tooth wear. Begg (1977) also stated that this increase in facial height could be attributed to continual tooth eruption to compensate for attritional processes.

Tallgren (1957) commented that though generalisations may be made regarding this increase in the vertical dimension of the face, only a longitudinal study could reveal the individual variations in this age change with respect to craniofacial morphology. In order to further investigate these changes, Forsberg (1979) instigated such a longitudinal cephalometric survey. The changes in skeletal relations and soft tissue profile were studied in subjects aged from 24 years to 34 years, with a 5 year interim study. A general increase in anterior facial height was noted, and this was attributed to a posterior growth rotation of the mandible. The angle Mandibular line/Nasion -Sella line angle was found to be increased, but no change in the gonial angle was recorded. This posterior rotation resulted in increased total and lower facial height, and explained the posterior movement of reference points on the anterior hard tissue surface of the chin. This rotation of the lower jaw was attributed to the eruption of the posterior teeth. Decreases in the angulation of the upper and lower incisors to the maxillary and mandibular planes was noted, and this was considered to be necessary to maintain the normal contact relationships of the incisors. Changes in the soft tissue variables were also recorded with ageing. The largest vertical increase was in the distance from the soft tissue Nasion to the junction of the lips. In addition, there appeared to be a continuous forward positioning of the apex of the nose, and a retrusion of the upper and lower lips. A posterior movement of the soft tissue pogonion was seen, corresponding to the same movement of the hard tissue point seen in both sexes. The changes seen in the 5 year survey were the same as those observed in the 10 year study, with numerically greater changes seen in the later survey. From these results, the conclusion was reached that specific patterns of changes in craniofacial morphology continue into adult life.

A similar study was conducted by Sarnas and Solow (1980) in which changes in linear and angular variables of soft tissue and craniofacial morphology were recorded with respect to ageing in the third decade of life (21-26 years). The results indicated a major increase in anterior facial height in the first half of the third decade. These alterations in facial form were studied by point and structure based analysis, whereby superimposition of tracings from longitudinally obtained radiographs expressed displacement of facial structures relative to common anterior cranial base reference points. As the changes expected were anticipated to be small, analysis of the method error of recording data from the radiographs was considered to be of great importance.

An increase in total anterior facial height was observed, the lower facial component contributing the greater part of this increase. By the superimposition of anterior cranial base structures, the position of the point Nasion was seen to vary considerably, and this emphasised the need for locating stable reference points. the results of the structure based analysis indicated a forward displacement of the maxilla and point analysis revealed a forward and downwards positioning of Nasion with advancing age. The mandibular line was observed to be displaced downwards, though with no alteration in its inclination to the cranial base. This is however contrary to the observations of Forsberg (1979) who noted an increase in the angle NSL/ML. The causal mechanism of the observed increase in facial height and alteration in jaw position with advancing age was not identified. Eruption of the lower anterior teeth was however noted, and this was considered to account for the vertical increase in the mandibular dentoalveolar component of the lower facial height. The causal factors behind this observation were also considered to be indeterminate. Soft tissue changes were seen to reflect the increase in anterior facial height, including an increase in the length of the nose and the lengths of the upper and lower lips. The depth of the nose showed no increase in relation to the length of its base, though the points determining this moved anteriorly with the maxilla, and it was thus inferred that the tip of the nose moved anteriorly and inferiorly with age, in accordance with the observations of Forsberg (1979). The result of these alterations was a net reduction in the facial profile angle. As the results of this study showed a greater increase in total anterior facial height in the age group 21-26 years than the results of the work of Forsberg (1979) (24-34 years age group), it was thus concluded that the major part of the increase in this dimension occurs during the first half of the third decade of life.

Reports in the literature thus demonstrate that facial growth continues in specific patterns throughout adult life, and evidence suggests that the greater part of this growth occurs in the first half of the third decade, with only minor differences between the sexes.

D. TREATMENT OF ATTRITION

1) Signs and Symptoms

Dental attrition presents a complex restorative problem in subjects with this form of advanced tooth wear and various rationales have been proposed by which management of such cases may be undertaken. In most circumstances, identification of the underlying aetiology is considered necessary, though this is not always possible. Appropriate preventive measures may then be taken, and once the wear is arrested, assessment of its effect on the vertical dimension of the occlusion is important. Once all these factors have been identified, restoration as required may be effected by conventional conservative or prosthodontic means.

i) Presenting complaints.

A patient may present with attrition in a variety of ways. Severe tooth wear may be observed as an incidental finding during routine dental examination, where tooth wear may be seen to be greater than would be expected with respect to the patient's age. Alternatively, the patient may present as a referral to specialist clinics from General Dental Practitioners (Goldhaber & Goldberg 1944, Mack & Allen 1968, Lewis & Smith 1973, Eccles 1982). A complaint that the patient may commonly present with is that of compromised aesthetics, due to the loss of anterior tooth substance through attrition. Alternatively, the patient may complain of pain or hypersensitivity due to the exposure of dentine through wear facets, and the subsequent stimulation of the pulp through thermal, chemical or mechanical means. Where attrition occurs at a greatly increased rate or is particularly severe (for example when combined with another form of tooth wear such as erosion) exposure or near exposure of the pulp may be a presenting symptom (Lewis & Smith 1973, Dahl & Krogstad 1975, Watson & Tulloch 1985, Williams 1987, Gankerseer 1987, Johnson 1987). The presence of rough or sharp teeth may also cause a patient to seek treatment through trauma to the oral soft tissues, particularly the tongue.

Tooth wear through attrition may produce steps in enamel, especially on the palatal surfaces of upper incisors, or cause the formation of concavities in exposed dentinal surfaces due to the poorer wear resistance of the dentine. This latter feature is however also characteristic of erosion (Renson 1975, Eccles 1982, Watson & Tulloch 1985). Impaired function or an obvious decrease in the vertical dimension of occlusion may result in patients requesting treatment, or may cause a general practitioner to seek a specialist conservative or prosthetic opinion on the patient's behalf (Brown 1980, Gankerseer 1987). Severe loss of vertical dimension may result in temporomandibular joint dysfunction, which again may be a presenting factor (Brown 1980). Many patients may however accept the wear of their teeth as part of the natural ageing process, and may not feel that treatment is indicated. In these cases, embarking on lengthy restorative procedures may be contra-indicated, and further wear may be monitored and prevented. Further intervention may then be carried out at a later stage, if and when the patient suggests a need for treatment (Russell 1987, Williams 1987).

ii) **Assessment of wear**

Once it is established that attritional tooth wear is, or has occurred in the past, it is necessary to evaluate the extent and rate of progress of the tooth surface loss.

The rate of loss of tooth tissue is often difficult to determine. Questioning the patient as to their own assessment of the rate of attrition, with particular reference to their awareness of the onset of symptoms, is a useful procedure. Most authors stress the importance of periodic review of such cases in order for the operator to assess whether or not the wear is ongoing, and if so, to give some indication of its rate. The existence of parafunction may influence the progression of wear, and the provision of a bite splint may allow estimation of attrition rates through the wear visible on such an appliance. Where lack of posterior support is a factor in the aetiology of attrition, assessment of the degree of support for the occlusion may give some indication as to the severity of the wear rates (Turner & Missirlian 1984, Watson & Tulloch 1985, Williams 1987).

In order to further assess the patterns and rates of wear due to attrition, various indices have been proposed by which a quantitative analysis may be made. Most examples of these indices are non-linear in nature and are based on subjective information and clinical evaluation by simple visual assessment. One of the earliest of such indices was described by Broca (1897). In this assessment, four degrees of tooth wear are described. The first stage described was wear of the enamel, without obliteration of cusps or exposure of dentine. The wearing down of cusps and subsequent exposure of dentine was regarded as the second stage. The third stage was described as the appreciable loss of the tooth crown, and the final stage was considered to be attrition extending down to the cervical margin of the tooth. Gustafson (1950) described a similar index for use in age determinations on teeth. The presence and degree of attrition was recorded in four stages, from no attrition present to attrition in enamel, dentine and extending to the pulp. The index thus described was also linked to other features of ageing teeth, such as the presence and amount of secondary dentine and cement.

Murphy (1959a) further developed the assessment of dentine exposure through attrition into a series of eight degrees of wear. Wear of enamel only was not considered in this index. The stages were recorded as follows: a) dentine exposed on one cusp only, b) dentine exposed on two cusps, c) dentine exposed on three cusps, d) dentine exposed in discrete areas on four cusps, e) coalescence of two dentinal areas, f) coalescence of three dentinal areas, g) coalescence of four dentinal areas with enamel remaining on the occlusal surface, h) enamel rim completely or partially surrounding the dentinal area on the occlusal surface.

Fishman (1976) described another similar assessment of the degrees of attrition. Four groups were described as follows:

0. No attrition
1. Cuspal attrition, with cuspal anatomy maintained
2. Elimination of cuspal anatomy, with fissure pattern remaining

3. No cuspal anatomy remaining, but attrition still within the crown

4. Attrition of the entire crown and beyond the cemento-enamel junction.

Indices such as these are described in order to quantify tooth substance loss, and are based on clinical criteria and are thus non-linear in nature. Olio et al (1987) noted this and pointed out that information obtained from indices such as these may be misleading and of little use in assessing the need for treatment. An index was proposed by which these problems could be overcome. Attrition was classified into three acceptable categories and two non-acceptable ones, each category being defined by written and photographic guidelines. Each tooth was given a rating in accordance with the index, and from these values, individuals were ascribed to one of the five categories, from which the need for treatment could be evaluated. Smith and Knight (1984a) similarly proposed an index of wear, in which the effect of different forms of tooth surface loss could be ascertained. In this index, wear is recorded from each surface of each tooth and given a value, depending on its extent. Employing this index on a sample of one hundred patients, a set of acceptable values was developed, with a maximum desirable value ascribed to each decade of life. Using this guide, wear rates could be assessed longitudinally as well as giving an indication as to the necessity for restorative treatment.

iii) Identification of aetiological factors

The identification of aetiological factors is often one of the first considerations in the management of patients with advanced dental attrition. Once this is established, prevention of further wear may be effected and a definitive treatment rationale prepared.

The aetiology of attrition has been considered in a previous section and many workers have discussed the importance of identifying these factors. These include the influences of diet and occupation (Goldhaber & Goldberg 1954, Eccles 1982, Pollman 1987), the presence of parafunctional activities (Dahl et al 1975, Renson 1975) and a lack of posterior support for the occlusion, resulting in advancing attrition of the anterior teeth (Basker et al 1983, Best 1987). Congenital abnormalities of the teeth, such as amelogenesis imperfecta or dentinogenesis imperfecta may also predispose to attrition (Turner & Missirlian 1984).

Attrition often occurs in conjunction with other forms of tooth wear, and it is important to distinguish whether or not this is the case when considering treatment of the worn dentition. Many workers have noted the association of erosion with attritional wear, and the loss of tooth tissue through erosive processes due to dietary influences, acid regurgitation, or environmental factors predisposes the dentition to attritional processes (Ten Bruggen Cate 1968, Lewis & Smith 1973, Johnson et al 1987). The difficulty in determining the aetiology of tooth wear was noted in a survey of patterns of tooth wear compared with aetiological factors. In this study, out of one hundred subjects, only 69 could be confidently allocated to a definite aetiological group. Often more than one form of tooth wear could be observed to occur in any one subject (Smith & Knight 1984b). In identifying the aetiology of attrition, abrasion and erosion in these subjects, the authors stressed the importance of systematic investigation of the patient's history with regard to the above factors. Other authors have similarly noted the difficulty in obtaining an exact aetiology for the various forms of tooth wear. The need for careful history taking with respect to diet, occupation, habits, past dental history and the presence of parafunctional activities is emphasised. The presence of sharp enamel edges may indicate attrition in the absence of other forms of tooth wear, and examination of any patterns of tooth wear may give such an indication of aetiology. Smooth enamel margins with no sharp edges, may for example, be strongly indicative of erosion rather than attrition in isolation. Similarly, localised attrition may be related to abnormal parafunctional mandibular excursions, whereas generalised attrition may indicate a dietary influence in addition to parafunction. The patterns of wear seen in abrasion however, are generally more characteristic, such as the V-shaped cercival notches produced by the over-zealous use of a toothbrush. These are often more easily distinguishesd from the patterns of wear produced by attrition (Watson & Tulloch 1985, Smith 1972, Williams 1987).

Once the aetiology of the process of tooth surface loss has been investigated, a treatment plan may be formulated to prevent further attrition and if necessay, restore the dentition.

2) Restorative Procedures

i) Prevention of further tooth tissue loss

Once attritional processes have been diagnosed and the aetiology identified, the prevention of further tooth tissue loss may be the first stage of treatment. The provision of a protective splint is the usual means of immediate prevention of tooth surface loss. This may be in the form of an acrylic, polythene or cobalt-chromium overlay appliance, which prevents tooth to tooth contact and thereby arrests the attritional process (Mack & Allan 1968, Renson 1975, Johnson et al 1987, Williams 1987). Gankerseer (1987) pointed out that acrylic splints may be unsuitable for long term use, as they may be prone to wear and fracture. Cobalt-chromium may be similarly unsuitable due to the compromising of aesthetics by the showing of metal on the incisal edges. A technique by which porcelain facings were bonded to a cobalt-chromium splint was described to overcome this difficulty. However, the use of acrylic splints remains the usual treatment of choice for prevention of further wear. Upper anterior bite planes worn nocturnally may depress the lower incisors and allow eruption of the posterior teeth in order to arrest anterior attritional wear. The use of tooth-coloured acrylic prevents compromising aesthetics and such appliances are well tolerated by patients (Charlton 1989).

Where lack of posterior support for the occlusion is implicated in the aetiology of attrition, the provision of partial dentures will relieve the load on the anterior segment and thus prevent further wear on the teeth (Mack & Allan 1968, Turner & Misirlian 1984). If bruxism is responsible for the attrition observed, the grinding of occlusal interferences and provision of a metal or acrylic splint for protective night wear and occlusal equilibriation is an appropriate means of preventing further wear (Renson 1975, Johnson et al 1987, williams 1987). Periodic review of all such appliances is necessary together with patient counselling where diet is involved in the aetiology of this form of tooth wear. Analysis of study model casts over a period of time will also enable the clinician to ascertain whether or not wear is progressing once preventive measures have been instituted (Williams 1987).

ii) **Restoration of the vertical dimension of occlusion**

Assessment of any changes in the vertical dimension of occlusion and the interocclusal space through attrition is often considered necessary. Careful determination of such changes and the resultant dimensions present is essential if restorations are likely to affect either of these vertical measurements. There is however considerable controversy as to the extent of changes in the occlusal vertical dimension, a feature which has been discussed in a previous section of the present report. Clinically, a reduction in vertical facial height is often noted in cases of severe attrition (Hamilton & Whitehead 1968, Renson 1975, Gankerseer 1987, Best 1987). However, the work of Tallgren (1957) suggests that some adaption to a reduced facial height may occur, resulting in only small increases in interocclusal clearance. Murphy (1959b) similarly discussed the possible mechanisms of compensation to the reduced vertical dimension of the lower face seen in attrition, and concluded that some adaption to this reduced dimension did occur. The implication of these findings is that in order to restore the worn teeth, it may be necessary to place restorations which encroach upon the interocclusal space, and an alteration of the present vertical dimension may be required. In order to test the patient's tolerance to this alteration, a bite raising appliance is usually advocated. This may be constructed from acrylic or cast metal, covering either the anterior segment or all of the teeth. This appliance may also serve the function of preventing further wear of the dentition. Appliances covering anterior teeth only may also provide space for restorations by allowing the eruption of posterior teeth, or possibly by intruding the anterior teeth (Mack & Allan 1968, Brown 1980, Watson & Tulloch 1985, Devlin 1985, Williams 1987, Dahl & Krogstad 1975, 1982, 1985, Charlton 1989). Once it has been established by means of a period of appliance wear whether or not the patient can tolerate an altered vertical dimension of the occlusion, final restoration may be effected.

iii) Restorative treatment

Final restoration of the worn teeth may be carried out by a variety of means. Conservative, prosthetic, or a combination of both techiques may be employed, depending on the space available and the complexity of treatment considered suitable for each individual patient.

Extraction of some or all of the remaining teeth, and provision of complete or partial dentures may be indicated where a simple treatment plan is preferred by the patient, or where caries of periodontal disease is extensive in addition to the attritional process (Williams 1987). Reduction of the clinical crowns and provision of complete or partial overdentures may also be undertaken, especially where lack of posterior support for the occlusion is important in the aetiology of the wear. In these cases, vertical space considerations are critical if this form of treatment is contemplated. Endodontics may be considered necessary, but multiple devitalisations are best avoided when a simple treatment plan is needed. Good patient compliance and a high standard of oral care is also essential for the long term success of such restorative procedures (Brown 1980, Basker et al 1983).

Restoration of the affected teeth using crowns is another alternative form of treatment. Porcelain bonded to metal is usually the type of anterior crown used, as minimum preparation is more appropriate for teeth suffering from advanced wear, and these restorations may withstand occlusal stresses more effectively. Where the tooth tissue loss is severe, post retained restorations may be indicated, the success of this form of treatment being dependent on satisfactory endodontics and a correct parallel sided post design (Charlton 1989). It is of course, essential to ensure that adequate space is available to place crowns in, and a bite raising appliance should be employed to provide this and protect the restorations once fitted. If posterior teeth are missing, a partial denture or fixed prosthesis, perhaps utilising occlusal overlays may also fulfil this function (Turner & Misirlian 1984, Brown 1980, Williams 1987).

The use of acid etch or pin retained ceramic or metal restorations may be successful, but will require the use of a protective splint to prevent failure. They are however easily placed and replaced. Utilising the above techniques, the dentition mutilated by attritional processes may be restored to an acceptable aesthetic standard and functional normality (Williams 1987).

In general, simplicity of approach and minimum interference are recommended, and occasionally "masterly inactivity" other than prevention is the treatment of choice in managing this complex restorative problem (Williams 1987).

E. SUMMARY

Dental attrition may be defined as the gradual and regular loss of tooth substance through tooth to tooth contact, such as may occur during mastication or parafunction, and presents in a variety of patterns (Renson 1975, Eccles 1982). This form of tooth wear may be differentiated from other mechanisms of tooth tissue loss such as abrasion and erosion, by its distribution and characteristic effects on the dentition, though it may occur in conjunction with these forms of tooth substance loss (Smith 1972, Lewis & Smith 1973, Renson 1975).

The aetiology of attrition includes the influence of dietary factors, especially the presence of a natural or unrefined diet (Begg 1954), which may also include extrinsic abrasive elements. Parafunctional activities such as bruxism may produce this form of tooth wear, and congenital abnormalities of the dental hard tissues may predispose an individual to attrition. Similarly, loss of posterior support for the occlusion, or abnormal occlusal contacts or jaw relationships may also influence the development of attrition (Renson 1975, Xhonga 1977, Best 1987). Occupation may be another factor involved in the pathogenesis of attritional wear, particularly if this involves activities which produce vibrational tooth contacts. Attritional toothwear increases with age as a normal finding, and though a distinct aetiology may be identifiable in cases of advanced wear, often the cause remains unclear (Hamilton & Whitehead 1968, Watson & Tulloch 1985, Pollman 1987, Williams 1987).

Early studies on attrition involve the examination of the dentitions of subjects living in primitive cultures, or the observation of archaeological material in which this form of advanced tooth wear is a common finding related to the natural diet of these populations (Begg 1954, Davies & Pederson 1955). Such a diet consists mainly of unrefined fibrous foods and may contain extrinsic abrasive substances such as sand or grit (Leigh 1933, Molnar 1972).

Attrition may occur in various patterns throughout the dentition. Generalised attrition may be seen in primitive cultures or associated with parafunctional activities (Molnar 1972, Xhonga 1977) whereas localised attrition may be a feature of occlusal collapse, lack of posterior support for the occlusion, or bruxism (Russell 1987).

In subjects showing generalised attrition, such as in Aboriginal cultures, a specific form of occlusal relationships has been described as attritional occlusion (Begg 1954). In this pattern of wear, the loss of tooth cusps and interproximal tooth tissue is compensated for by occlusal and mesial migration of the teeth. This may lead to the development of an edge to edge bite, and it has been suggested that this form of occlusion may be associated with improved masticatory efficiency (Russell 1982).

The effects of attrition on general oral health are also documented in the literature. This form of tooth wear has been associated with an improvement in the general standard of dental health, attributed to the ablation of potential stagnation sites by occlusal and interproximal tooth wear. The reduction of the mesio-distal dimensions of the affected teeth may be associated with a decreased incidence of crowding and malocclusion. The freedom of masticatory movements associated with the lack of tooth cusps may similarly be associated with a decrease in the incidence of temporomandibular joint disorders. The incidence of this form of severe generalised tooth wear in modern populations is however rare (Ainamo 1972, Newman 1974, Begg 1977, Carlsson 1985).

Attrition produces characteristic effects on individual teeth, including well defined patterns of dentine exposure (Murphy 1959a, 1968). Pulpal reaction to attrition involves the formation of secondary irregular dentine within the subadjacent pulp. There appears to be a low incidence of inflammatory response within the pulpal tissue, though a tendency towards fibrous replacement has been observed in teeth suffering from advanced wear (Tronstad & Langland 1971). Exposure of the pulp may occur where attrition is rapid or combined with another form of tooth wear, and when this occurs necrosis is inevitable. It has been noted however, that sterile death of the pulp may occur as a result of attritional wear, a process which is usually painless for the patient (Russell 1987).

Attrition has been considered as being both physiological and pathological. Some authors have described all degrees of this form of tooth wear as being within normal limits, this concept being based on observations made on primitive populations where attritional occlusion is a normal finding. Other authors have stated that considering the adverse effects that attrition may have on the dentition, it may be regarded as pathological in all cases, particularly when it occurs in a generalised form inappropriately in modern populations, or is confined to single groups of teeth (Klatsky 1939, Berry & Poole 1974, Pindborg 1977). In general, whether or not attrition is considered as pathology or as being within normal physiological limits depends on the context in which the wear takes place, the age of the patient and the rate of wear, and whether or not attrition renders the tooth vulnerable to functional loading or other dental disease (Russell 1987).

The effects of attrition are not confined entirely to the teeth. Changes in arch width and length have been noted, as have alterations in interarch relationships and the buccolingual plane of occlusion. Incisor relationships may be similarly affected, leading to the development of an edge to edge bite. Evidence indicates that the occlusal vertical dimension may become reduced with increasing degrees of attrition. The interocclusal clearance may become increased, though this is not always the case. Other skeletal relationships are also affected. A reduction in the gonial angle and lower and total facial heights occur, and alterations of the incisor angular relations have been observed. Similarly, a reduction in the angulation of the articular eminence has also been noted with advancing attrition. (Tallgren 1957, Murphy 1964, Fishman 1976, Begg 1977, Granados 1979, Krogstad & Dahl 1985).

The above changes in skeletal morphology and dento-facial relations have been studied as possible compensatory mechanisms to functional tooth attrition. Evidence suggests that alveolar growth and continual tooth eruption together with these changes may partially compensate for the loss of tooth tissue through attrition (Murphy 1959b, Begg 1977, Berry & Poole 1976).

Reports in the literature indicate that age changes in skeletal morphology occur in the skull in addition to those attributed to attrition throughout the adult period of life. An increase in total and lower facial height occurs with advancing age, particularly within the first half of the third decade, but continuing up to the eighth decade. Changes in the soft tissue profile may also be observed, corresponding to these hard tissue differences (Lasker 1953, Tallgren 1957, Forsberg 1979, Sarnas & Solow 1980).

Patients suffering from attritional tooth wear present in a variety of ways. Tooth wear may be observed as an incidental finding on routine dental examination, or the patient may complain of compromised aesthetics, hypersensitivity, or rough or sharp teeth. Alternatively, patients may present to specialist clinics as referred cases or complaining of temporomandibular joint problems (Eccles 1982, Watson & Tulloch 1985, Gankerseer 1987).

Treatment consists of identifying aetiological factors, assessing and monitoring wear rates, and if further intervention is required, restoring the teeth by conservative, prosthetic or combined techniques (Lewis & Smith 1973, Renson 1975, Eccles 1982, Johnson et al 1987). Careful consideration of the effects of the wear on the vertical dimension of occlusion is essential to avoid possible post-operative complications, and trial appliances may be employed to test the patient's tolerance to proposed alterations of the patient's occlusal vertical dimension. Such appliances also may serve the function of preventing further wear, or providing space for restorations by allowing selective tooth eruption (Dahl et al 1975, Turner & Missirlian 1984, Best 1987, Johnson et al 1987, Charlton 1989).

Treatment plans may be influenced by the patient's views, and complex rationales may be inappropriate in many cases. In general, simplicity of approach, and careful consideration of all the factors involved is essential to solve the complex restorative problem of advanced attrition (Williams 1987).

CHAPTER 3

SUBJECTS

The study sample consisted of 35 patients (27 males, 8 females) attending the Conservation Department of Edinburgh Dental Hospital. These patients were obtained as sequential referrals from General Dental Practitioners operating with the General Dental Service in the Lothian Health Board area.

The mean age of the sample was 48.4 years (median age 47.0 years) ranging from a minimum of 30 years to a maximum of 78 years. A graph describing the age distribution of the sample group is shown in Fig 2.

All the study sample subjects were selected on the basis of exhibiting advanced dental attrition through which more than one third of the original estimated clinical crown length of either upper or lower incisors had been lost. Only subjects with natural central and lateral incisors were included in the sample, and no patient who had undergone or was currently having any form of occlusal therapy or prosthetic alteration of their occlusal vertical dimension was included in the study category. All patients in the study sample were of British ancestry and were normally resident within the Lothian region (Fig 3).

FIGURE 2 Age distribution of the study sample.

FIG. (2)

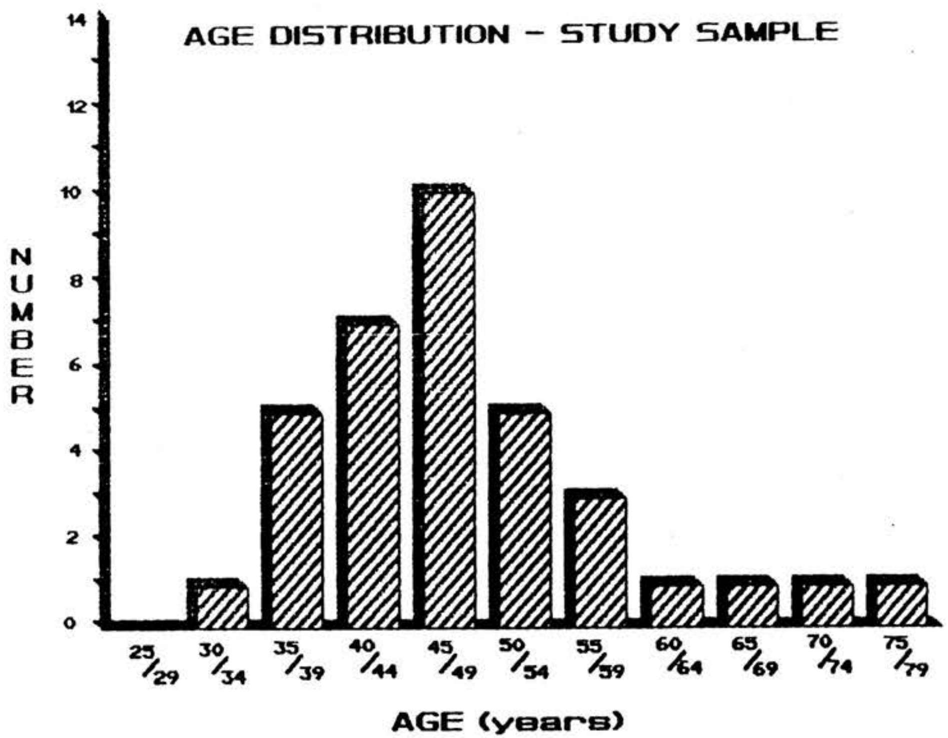
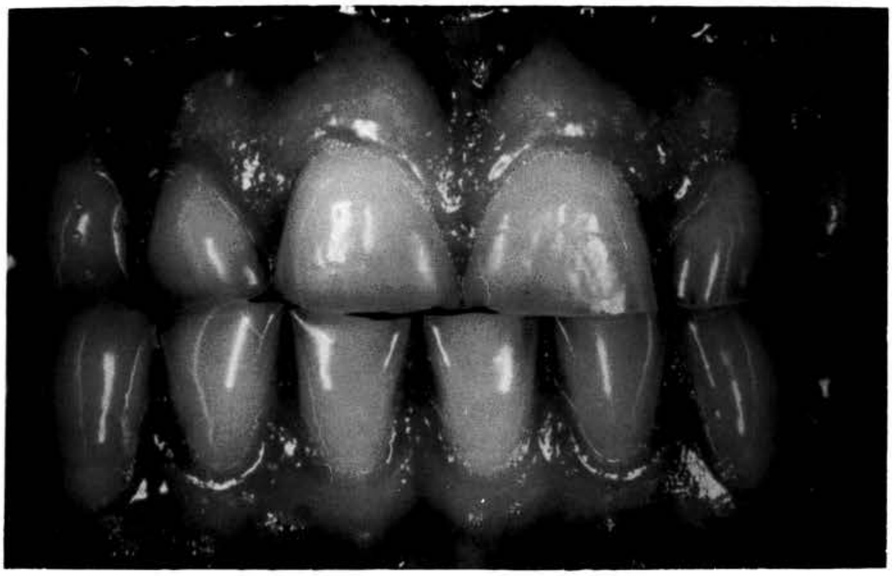

AGE DISTRIBUTION - STUDY SAMPLE
NUMBER
14
12
10
8
6
4
2
0
25/29
30/34
35/39
40/44
45/49
50/54
55/59
60/64
65/69
70/74
75/79
AGE (years)

FIGURE 3 Subjects with advanced attrition.



The control group consisted of 40 patients (18 males, 22 females) who had been referred for orthodontic assessment in the Orthodontic Department of the Edinburgh Dental Hospital within 5 years previous to the commencement of the study. All patients in the control group had previously had lateral cephalometric radiographs taken as part of this orthodontic assessment, and the radiographs were obtained randomly from a pool of radiographic data held within the records of this department. All radiographs had been exposed when the subject was in or beyond the third decade of life, and no radiograph was included that had not been obtained using the same equipment employed for the study sample.

The mean age of the control group was 26.1 years (median age 25.0 years) ranging from a minimum of 20 years to a maximum of 36 years. A graph describing the age distribution of the control group is shown on Fig 4, and Tables 1 and 2 describe the age and sex distribution of both study and control categories. All the patients in the control group were of British ancestry and were normally resident within the Lothian region.

1. STUDY SAMPLE SUBJECTS

The material was collected during the period of the study from January 1988 to November 1989. The Dental Hospital in Edinburgh provides a consultant service for practitioners within the General Dental Service in the Lothian Health Board regions and the data for the study sample was collected from sequential referrals to one specialist clinic within the Conservation Department. Ethical

FIGURE 4 Age distribution of the control group.

FIG. (4)

AGE DISTRIBUTION – CONTROL GROUP

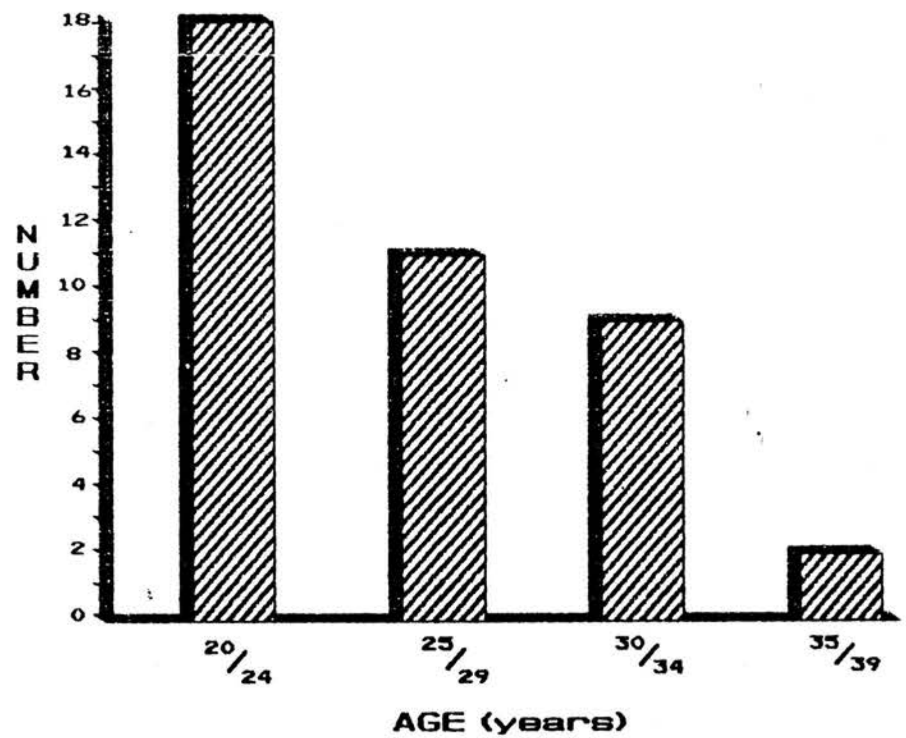


Table 1

Age distribution of control group and study sample

Category	$\bar{X}$	Standard Deviation	Range
Study sample	48.429	10.294	30 - 78
Control group	26.125	4.392	20 - 36

Table 2

Sex distribution of control group and study sample

Category	Male N (%)	Female N (%)	Total
Study sample	27 (77.14)	8 (22.86)	35
Control group	18 (45.00)	22 (55.00)	40

approval for the research was obtained from the Lothian Area Dental Ethical Committee prior to commencing the study. Approval from the consultant clinician was also obtained prior to the collection of any data for the study. Informed consent was similarly obtained from each patient prior to taking any radiographs.

All assessments of suitability for inclusion in the study were carried out by the author, and all radiographs were taken by the same radiographer using the same technique and apparatus (Fig 5).

No patients were included in the study sample who exhibited any form of tooth wear other than attrition or whose loss of tooth tissue could be attributed to severe malocclusion.

2. CONTROL GROUP SUBJECTS

All radiographs used in the control group category had been used as part of an orthodontic assessment in the Edinburgh Dental Hospital. All radiographs were selected by the author, and none of the patients had received any orthodontic treatment at the time of exposure of the radiograph. All radiographs selected were obtained using the same equipment employed for the radiography of the study sample subjects. No subject was included who had any fixed prosthesis present at the time of radiography, and all radiographs were scrutinised prior to inclusion to exclude any severe tooth wear or craniofacial deformity (Fig 6).

Tables and figures describing the age and sex distribution of data for the sample group and control group may be found on Figures 2 and 4, and Tables 1 and 2.

FIGURE 5 Lateral cephalometric radiograph from the study sample.

FIGURE 6 Lateral cephalometric radiograph from the control group.

for the sample group and control group may be found on Figures 2 and 4, and Tables 1 and 2.

CHAPTER 4

METHODS

1. CLINICAL PROCEDURES USED IN THE STUDY

For patients in the control group (N=40) a cephalometric lateral skull radiograph was taken as part of an orthodontic assessment at the Edinburgh Dental Hospital. Radiographs selected for this group were identified as previously described (Fig 5,6).

For patients in the study sample (N=35), following examination and having been determined as being suitable for inclusion in the present study, a similar lateral cephalometric radiograph was taken. All radiographs were scrutinized to ensure hard and soft tissue cranial references were included on the film, and that a correct centric occlusion of the dentition was established.

Prior to taking the radiograph, any prosthesis worn by the patient was removed and the occlusal relationships examined. Any patients who showed a tendency to posture the mandible anteriorly on closure were guided manually into centric occlusion and shown the desired relationship by means of a hand mirror. The patient then rehearsed achieving the necessary occlusal relationship under supervision, and once this was obtained satisfactorily, the lateral cephalometric radiograph was taken.

Scrutiny of the radiographs was carried out prior to the patient's departure to determine if any repeat exposure was required. Failure to record all the necessary soft tissues and skeletal structures, incorrect occlusal registration and poor image quality were regarded as the main criteria in determining whether or not repeat exposures were necessary.

All radiographs were obtained using the same apparatus and all the patients in the control and the study samples were positioned for the radiography and had the exposures taken by the same operator. Any radiographs that failed to satisfy the criteria determining them to be suitable for digitising were retained and used as an aid to accurate identification of cephalometric landmarks. Point location reproducibility of these reference landmarks was tested by duplicate determinations as part of the present study.

2. MEASUREMENTS OBTAINED FOR THE STUDY

For each subject, lateral cepahlometric radiographs were obtained with the patient's teeth in centric occlusion. Once processed, the radiographs were inspected to ensure that all the desired skeletal and soft tissue structures had been recorded, and that the patients teeth had remained in the correct relationship whilst the film was exposed. Reference points defining reproducible hard and soft tissue locations were identified on the radiographs and transferred to acetate tracing paper.

Co-ordinate data defining the location of these reference points were written to computer disk files with the aid of a digitiser and an existing computer programme modified for use in the study. Linear and angular dimensions of soft tissue and craniofacial form were then computed to enable statistical analysis of the data to be carried out.

A. <u>**Equipment and procedures used in the study**</u>

i) **Cephalometric**

The cephalometric radiographs were obtained using a Siemens Orthoceph 5 Cephalostat (220v supply) (Fig 7). The patients were positioned in the natural erect stance with all radio-opaque material removed from the head and neck region. The ear rods of the cephalostat were adjusted to suit each individual patient, and positioned just within the external acoustic meatus. The anterior measure of the cephalostat was adjusted to rest on the bridge of the nose, and the patients were instructed to hold the teeth together in centric occlusion. Occlusal relationships were checked visually prior to exposure.

The film was placed on the right side of the face with the median plane 21cm from the film. The film focal distance was 184cm, and the size of the focal spot was 0.6 x 0.6mm with the central ray passing through the ear rods (Fig 8).

Total filtration on the unit was 2.5mm aluminium and exposures were carried out at 75kV and 12mA for 1.2 seconds. Trimatic 'C'

FIGURE 7. Siemens Orthoceph - 5 cephalostat.

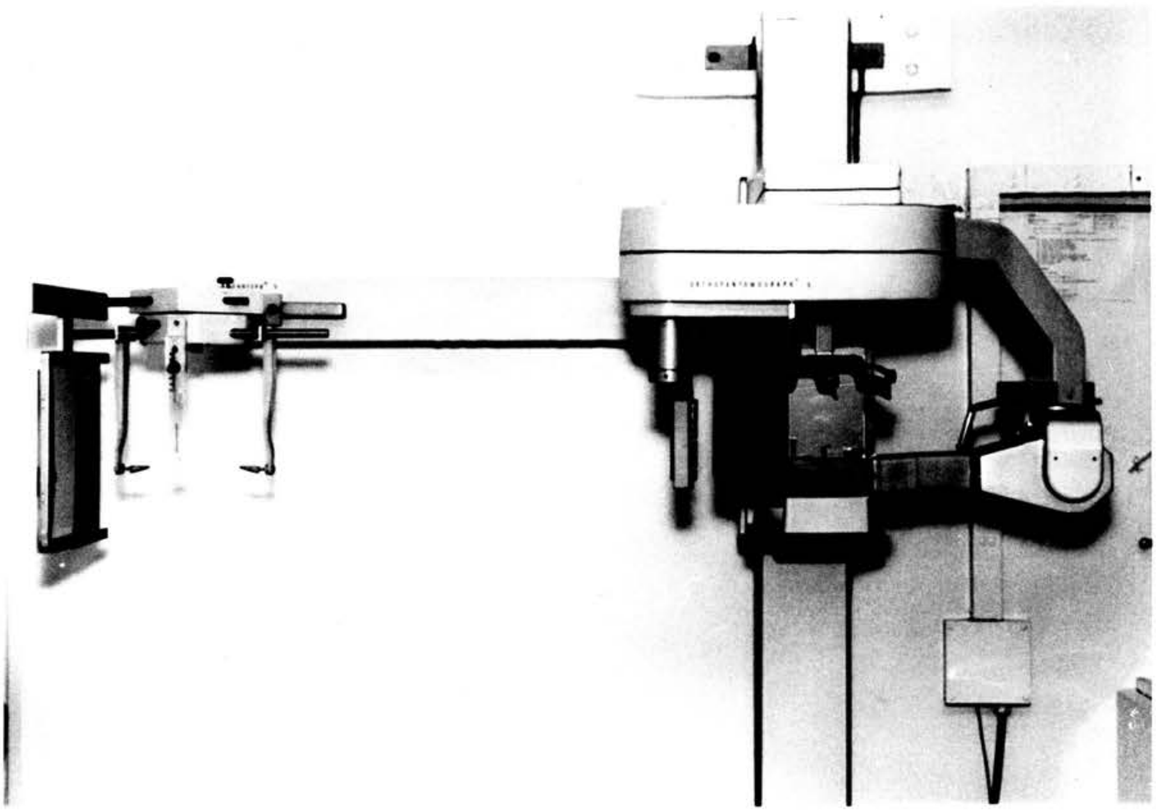
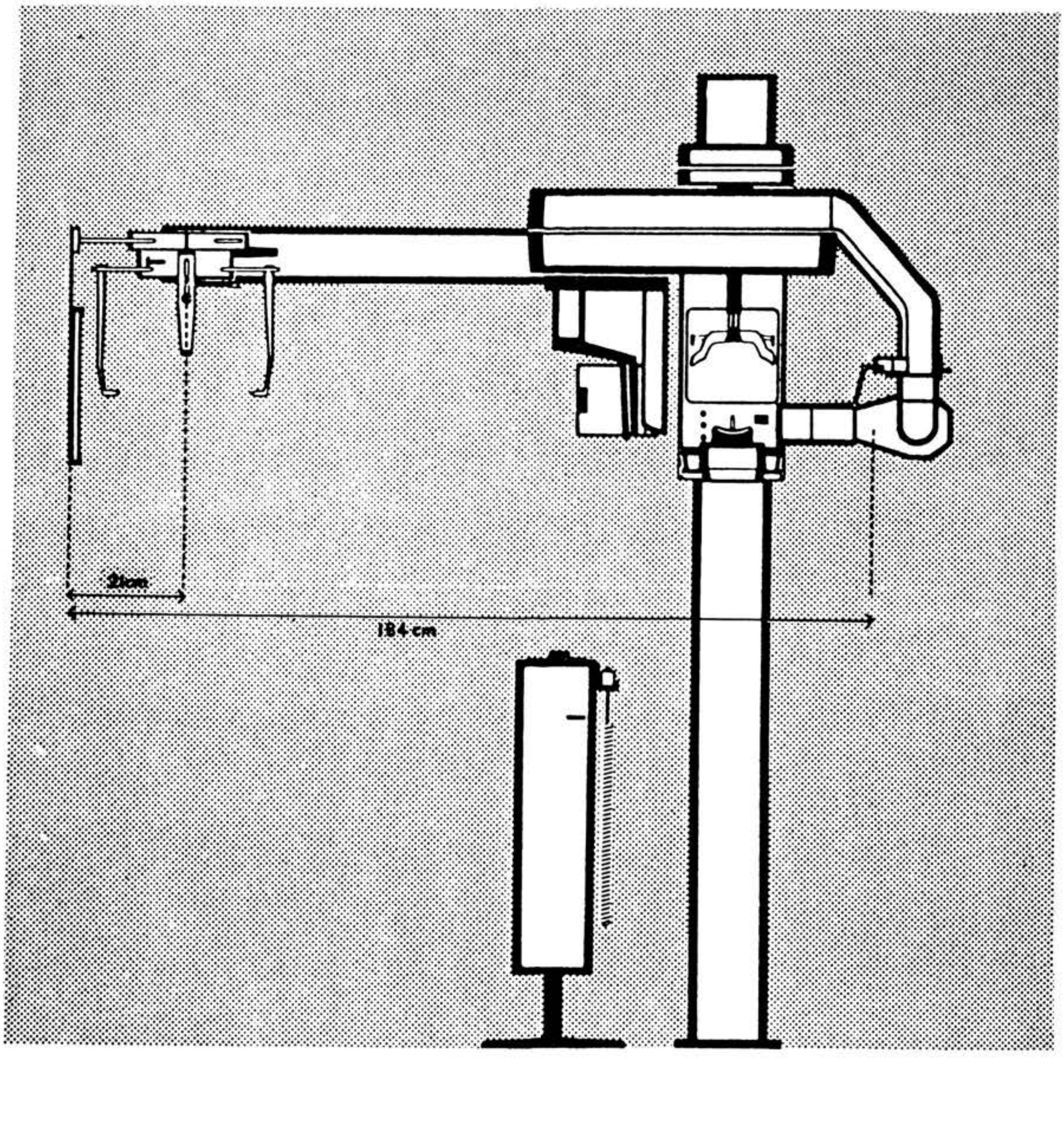


FIGURE 8. Siemens Orthoceph - 5 cephalostat (schematic).


21cm
184 cm

cassettes containing Kodak X-omat S film and Trimax Y16 calcium tungstate screens were used. The dimensions of the film and screens were 24 x 30cm (Fig 9).

Reduction in radiation dosage to the patient was obtained using lead aprons, rare earth intensifying screens (Trimax Y16 calcium tungstate) and high speed film (Kodak X-omat S). All radiographs were obtained using the same apparatus and technique in order to avoid errors due to magnification.

ii) **Digitiser**

Cephalometric analysis of the lateral skull radiographs from the control and study samples was carried out by comparison and statistical assessment of co-ordinate data held on computer disk file. The co-ordinate data described the location of 51 reproducible points defining cephalometric landmarks on the radiographs. These points delineated 53 linear and angular variables of craniofacial and soft tissue morphology (Tables 3,4 5).

Each lateral cephalometric radiograph was secured to a light box by means of adhesive tape, and a sheet of acetate tracing paper was positioned over the radiograph, ensuring that all skeletal, dental and soft tissue structures were located centrally on the tracing paper. The acetate sheet was then similarly secured to the light box and radiograph, again by means of adhesive tape (Fig 10).

The 51 cephalometric points were then located and transferred to the acetate tracing paper using an ultra-fine waterproof marker pen.

FIGURE 9. Trimatic C Cassette with Trimax Y-16 screen and Kodak X-omat S film.

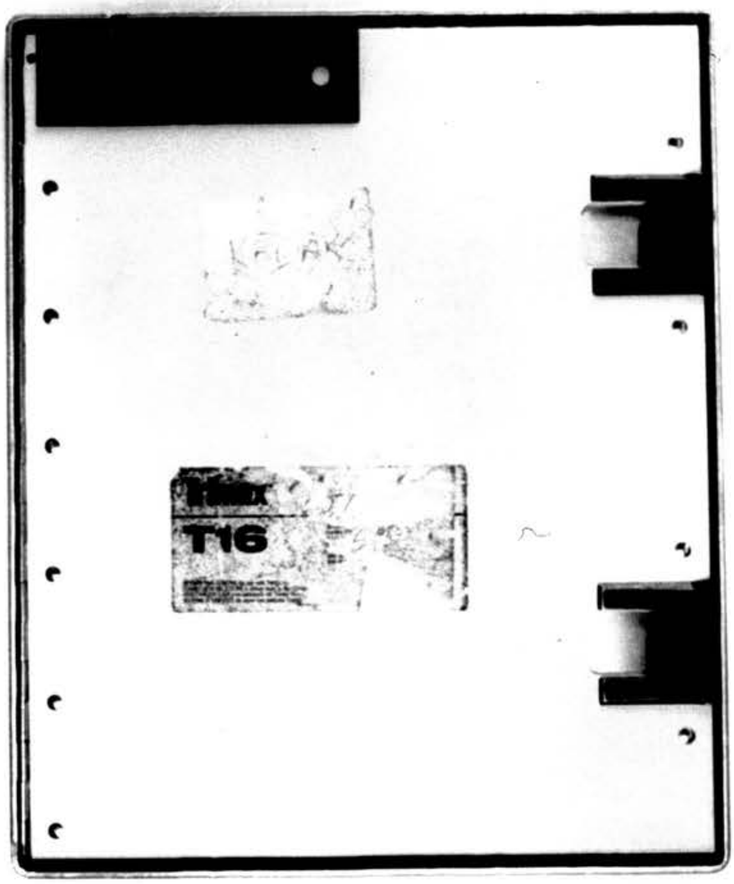

T16

Table 3

Digitiser Variable Descriptions

Variable Number	Variable Name	Variable Parameters 1	2	3	4	5
1	n-s	6	5	0	0	0
2	n-sp	6	8	0	0	0
3	n-gn	6	16	0	0	0
4	s-ba	5	3	0	0	0
5	s-ar	5	12	0	0	0
6	s-pm	5	9	0	0	0
7	s-tgo	5	14	0	0	0
8	sp-gn	8	16	0	0	0
9	ar-tgo	12	14	0	0	0
10	sp-pm	8	9	0	0	0
11	ss-pm	29	9	0	0	0
12	pgn-cd	17	10	0	0	0
13	pg-tgo	18	14	0	0	0
14	sp-is	8	31	0	0	0
15	ii-gn	32	16	0	0	0
16	n-s-ba	6	5	3	0	0
17	n-s-ar	6	5	12	0	0
18	pm-s-ba	9	5	3	0	0
19	s-n-sp	5	6	8	0	0
20	s-n-ss	5	6	29	0	0
21	s-n-sm	5	6	19	0	0
22	s-n-pg	5	6	18	0	0
23	ss-n-sm	29	6	19	0	0
24	ss-n-pg	29	6	18	0	0
25	NSL/NL	6	5	8	9	0
26	NSL/ML	6	5	16	15	0
27	NL/ML	8	9	16	15	0
28	NSL/MBL	6	5	17	10	0
29	ML/RL	11	13	16	15	0
30	$1L_s$ /NL	31	30	9	8	0
31	$1L_i$ /ML	15	16	32	21	0

Table 3 (continued)

Digitiser Variable Descriptions

Variable Number	Variable Name	Variable Parameters 1	2	3	4	5
32	oj	31	26	0	0	5
33	ob	32	26	0	0	6
34	is_1-is_2	24	25	0	0	0
35	ii_1-ii_2	22	23	0	0	0
36	is-as	31	30	0	0	0
37	ii-ai	32	21	0	0	0
38	ns-$_{sns}$	34	40	0	0	0
39	ns-prn	34	37	0	0	0
40	lnt to n-ss	38	6	29	0	7
41	s-n_s-unt	5	34	36	0	0
42	sto to NL	43	8	9	0	7
43	s-n_s-ss_s	5	34	41	0	0
44	sn to lnt-ls	40	38	42	0	7
45	ls to NCL	42	38	48	0	7
46	sto to ML	43	16	15	0	7
47	s-n_s-sm_s	5	34	46	0	0
48	sm_s to li-pg_s	46	44	47	0	7
49	li to NCL	44	38	48	0	7
50	ss_s-n_s-sm_s	41	34	46	0	0
51	sto to OL_s	43	31	27	0	0
52	s-n_s-pg_s	5	34	47	0	0
53	NFL/NCL	33	36	48	38	0

Table 4

Digitiser Variable Parameters - Description

Variable Parameter	Description
1.	Cephalometric reference point (1-53)
2.	Cephalometric reference point (1-53)
3.	Cephalometric reference point (1-53)
4.	Cephalometric reference point (1-53)
5.	Digitiser specifying value (0-7)

Table 5

Digitiser Specifying Value - Description

Value	Description
0.	Angle calculated, either +ve or -ve degrees
1.	Angular value, given as 360° - angle
2.	Angular value given as 180° - angle
3.	Angular value given as 90° + angle
4.	Index of distance [(1-2)/(3-4) x 100]
5.	Distance +ve or -ve with respect to x-axis
6.	Distance +ve or -ve with respect to y-axis
7.	Perpendicular distance from 1 to Line 2-3.

FIGURE 10. Light box with radiograph and tracing acetate.

The points were subsequently numbered in a sequence defined for the study (Table 6,7). Once the transfer of numbered cephalometric points was complete, the tracing was removed from the radiograph and light box in preparation for digitising.

Co-ordinate data collection was carried out using a GTCO Digipad model 5 digitiser (Fig 11). Point reproducibility by the digitiser and linearity testing of the apparatus was carried out and is reported as part of the study.

The dimensions of the machine were 52.5cm x 52.5cm x 2.9cm and the size of the active area was 30.5cm x 17.2cm. Each acetate tracing bearing the 51 cephalometric points measured 25.5cm x 20.5cm and was secured within the active field by means of adhesive tape, ensuring that all the points on the acetate sheet lay within the active field. The cursor was subsequently placed over each point in the defined numeric sequence (Fig 12,13 14). The machine emitted an audible signal to indicate that co-ordinate data had been recorded for each point.

An IBM PC/XT model 256 computer was used for the study (Fig 15) and computer programmes to record the X and Y co-ordinate position of each point were modified from those used in a previous investigation (Sandham 1987), the data thus obtained being written to computer disk files to enable statistical comparisons to be carried out.

To determine that each acetate had been correctly digitised, the co-ordinates for each tracing were used to create a pen plot of the

Table 6

Sequence of digitising of skeletal points located on the lateral cephalometric radiograph.

Sequence	Reference point	
1.	Origin)	
2.	Vertical axis)	Vertical axis reference points
3.	ba	
4.	p	
5.	s	
6.	n	
7.	or	
8.	sp	
9.	pm	
10.	cd	
11.	rls	
12.	ar	
13.	rli	
14.	tgo	
15.	go	
16.	gn	
17.	pgn	
18.	pg	
19.	sm	
20.	id	
21.	ai	
22.	ii_1	
23.	ii_2	
24.	is_1	
25.	is_2	
26.	int	
27.	mms	
28.	pr	
29.	ss	
30.	as	
31.	is	
32.	ii	

Table 7

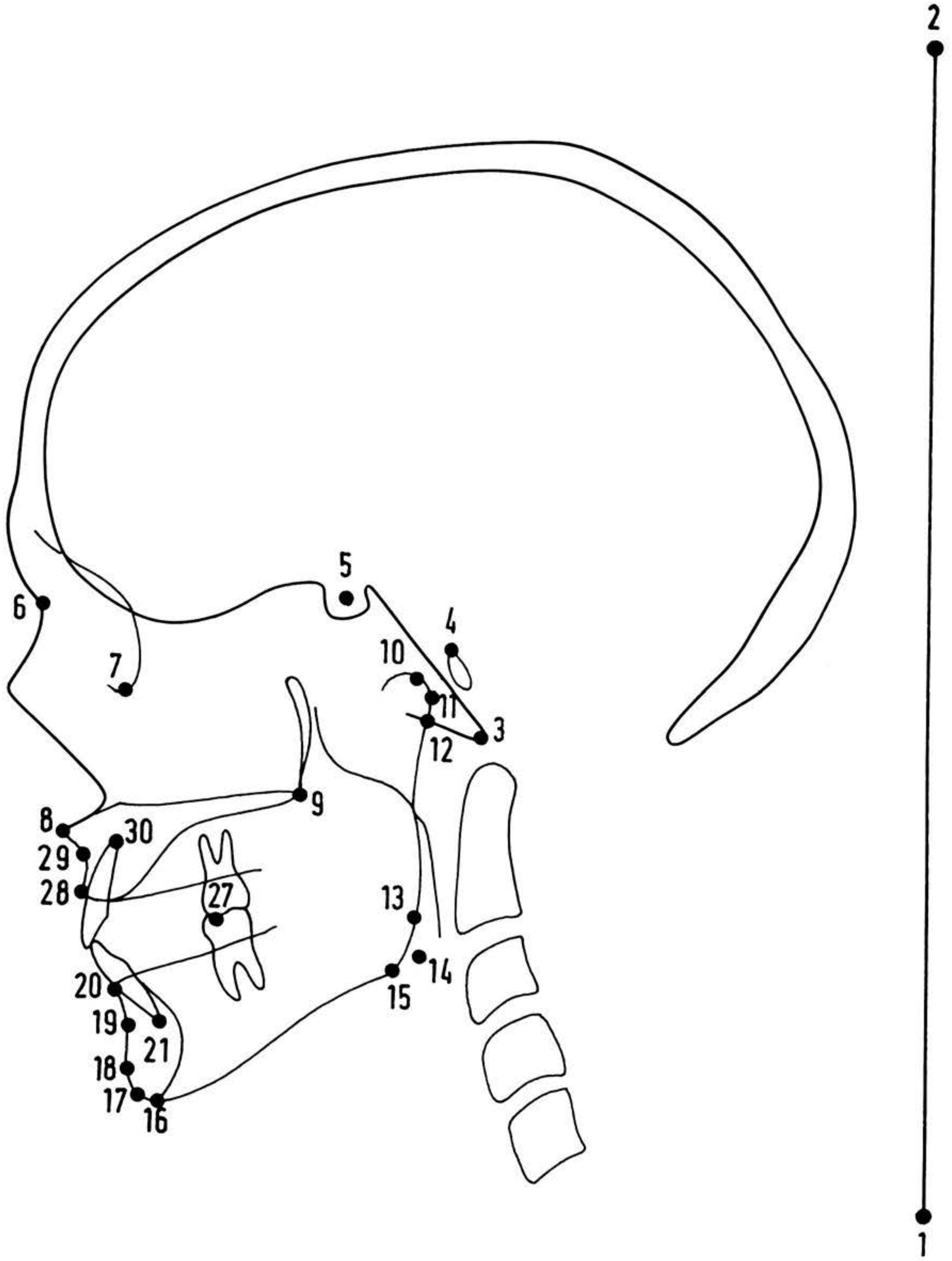
Sequence of digitising of soft tissue points located on the lateral cephalometric radiograph.

Sequence	Reference point
33.	ft
34.	n
35.	ds
36.	unt
37.	prn
38.	lnt
39.	nst
40.	sn
41.	ss
42.	ls
43.	sto
44.	li
45.	llt
46.	sm
47.	pg
48.	ct
49.	pgn
50.	gn
51.	sme

FIGURE 11. Digipad 5 digitiser and cursor.

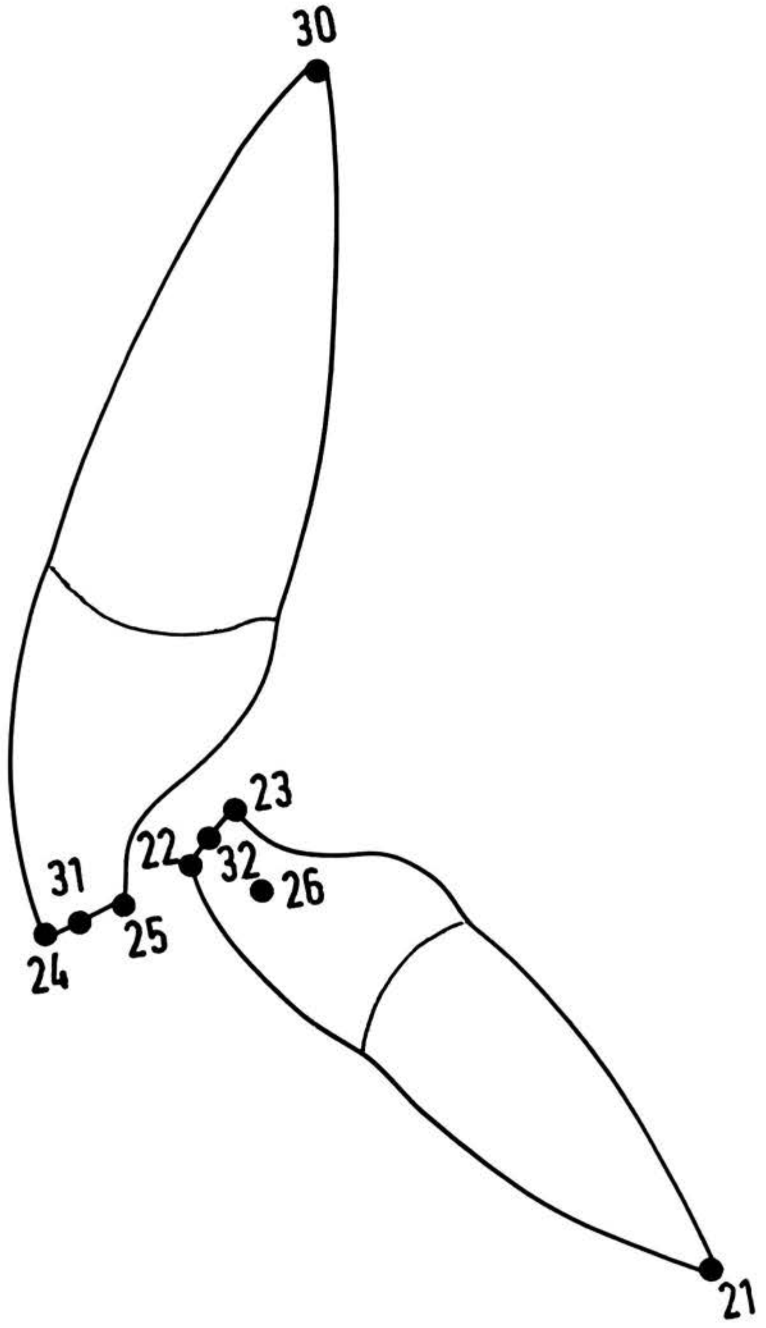

WARNING
GTCO Corporation

FIGURE 12. Sequence of digitising of the skeletal reference points located on the lateral cephalometric radiograph.



2
5
6
4
10
7
11
12
3
8
30
9
29
28
27
13
14
20
15
19
21
18
17
16
1

FIGURE 13. Sequence of digitising of incisal reference points located on the lateral cephalometric radiograph.



30
23
22
32
26
31
25
24
21

FIGURE 14. Sequence of digitising of soft tissue reference points located on the lateral cephalometric radiograph.

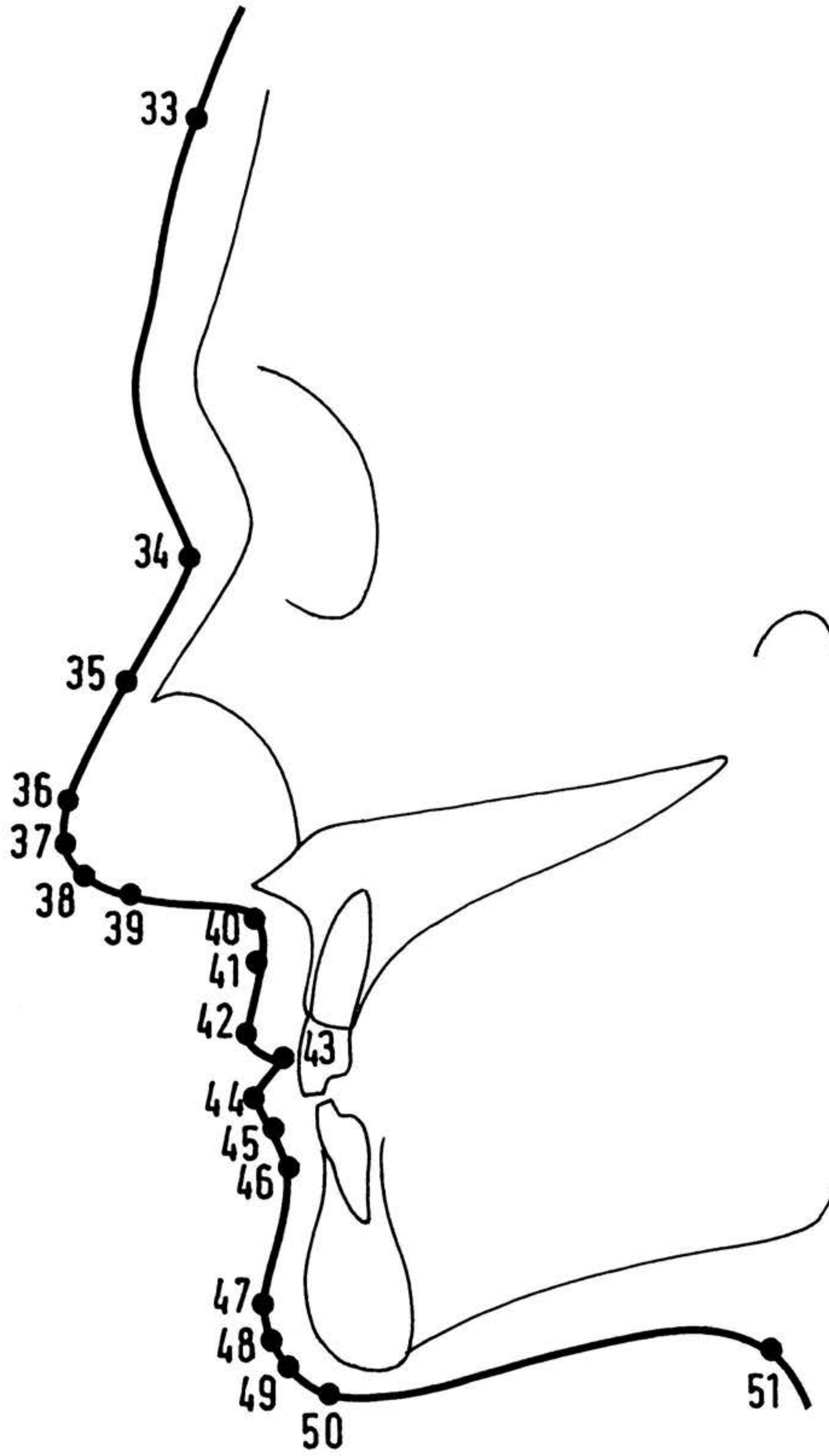

33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51

FIGURE 15. IBM PC/XT Model 256 and monitor.


IBM
IBM
IBM

cephalometric points for each subject, inspection of which allowed identification of errors in point location or digitisation sequence (Fig 16,17).

iii) **Statistical**

The co-ordinate data describing the position of 53 linear and angular variables of craniofacial form, recorded by the digitiser and written to computer disk file with the aid of the programme modified for the study, were then used to calculate the linear and angular dimensions defined in the variable description file (Table 3).

These calculations were carried out for both the control group and the study sample, with the results stored on computer disk file.

Statistical comparisons were made between the control group and the study sample using the facilities of the Edinburgh Regional Computing Centre (ERCC). Descriptive statistics were obtained using the Statistical Package for the Social Sciences (SPSS) programme.

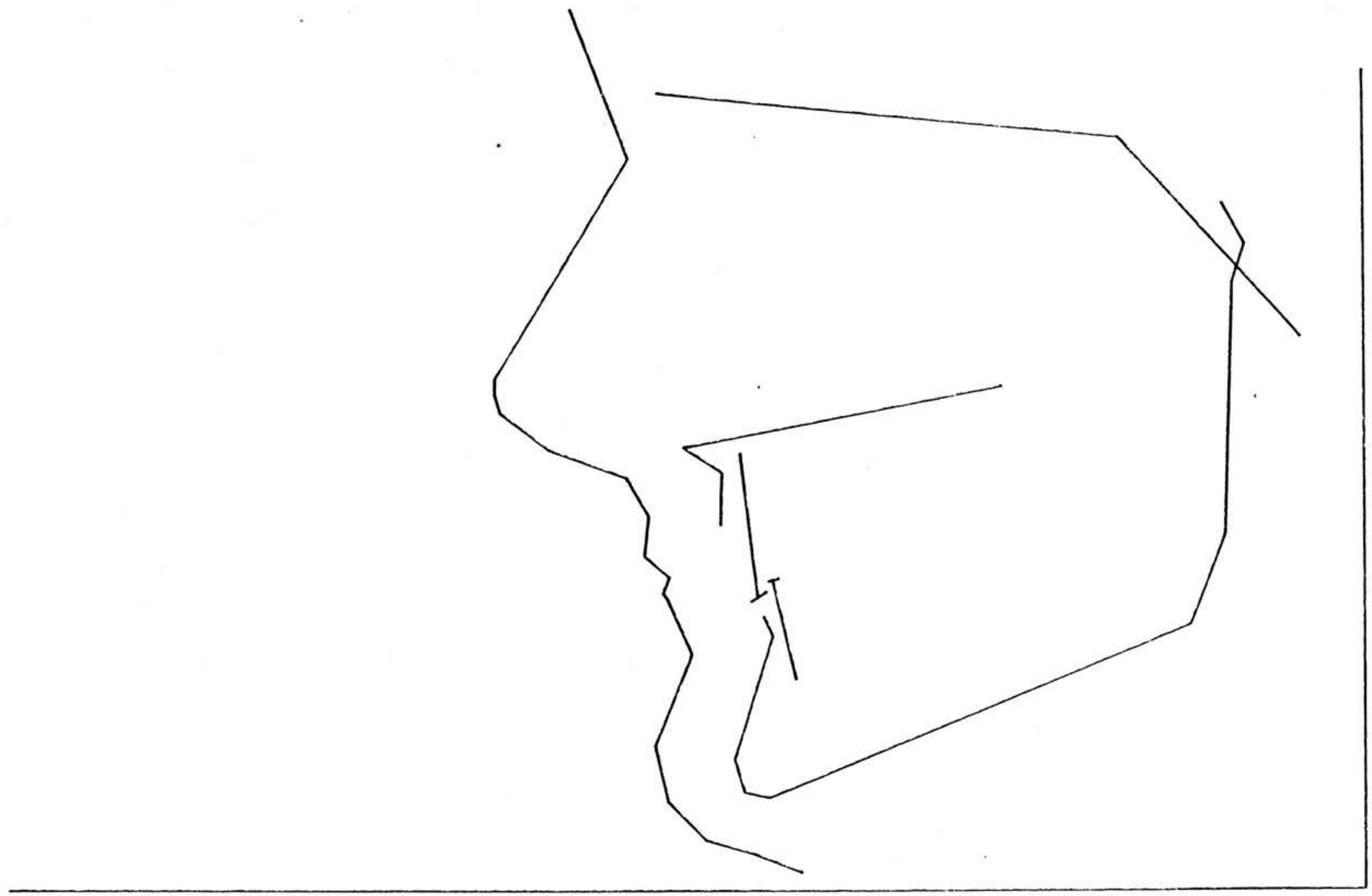
B. Definitions of the measurements

The reference points identified and planes defined on the cephalometric lateral skull radiographs are shown in figures 18 to 23). The 51 points defined on the lateral skull radiograph of each patient enabled a detailed craniofacial and dento-alveolar analysis to be carried out. The numeric cephalometric points and the sequence used during digitising in the investigation are similarly

FIGURE 16. Hewlett-Packard Plotter.


HEWLETT PACKARD
Response Centre
Linkline
0345 414 500
WARRANTY
00/058
FAMILY ID No
DATE OF EXAMINATION 23/10/1989
PLOTTED ON 28/ 8/1990

FIGURE 17. Pen plot derived from 51 reproducible points digitised from the lateral cephalometric radiograph.



PATIENT as12
DATE OF EXAMINATION 6/11/1989
PLOTTED ON 19/10/1990

shown in tables 6,7. The variable descriptions of the linear and angular dimensions are shown on table 3 with further explanatory description in tables 4,5.

i) Reference points used in the study (Fig 18,19,20)

ai	Apex Inferius	The apex of the root of the most prominent lower central incisor.
ar	Articulare	The intersection between the external contour of the cranial base and the dorsal contour of the condylar head or neck.
as	Apex Superius	The apex of the root of the most prominent upper central incisor.
ba	Basion	The most postero-inferior point on the anterior margin of the foramen magnum.
cd	Condylion	The most supero-posterior point on the condylar head.
ct	Chin Tangent Point	The lower tangent point of the nose-chin line.
ds	Dorsum nasi	The point located at the greatest convexity or concavity of the dorsum nasi.
ft	Frontal Tangent Point	The upper tangent point of the nose-frontal line.

gn	Gnathion	The most inferior point on the mandibular symphysis.
gn_s	Soft Tissue Gnathion	The soft tissue point overlying gn.
go	Gonion	The most inferior and posterior point on the angle of the mandible where the bisector of the posterior and inferior border tangents meets the mandibular outline.
id	Infradentale	The most antero-superior point on the lower alveolar margin.
ii	Incision Inferius	The midpoint of the incisal edge of the most prominent lower central incisor.
ii_1	Incision Inferius 1	The anterior margin of the incisal edge of the most prominent lower central incisor.
ii_2	Incision Inferius 2	The posterior margin of the incisal edge of the most prominent lower central incisor.
int	Incision Occlusale	The projection of ii on OL_s.
is	Incision Superius	The midpoint of the incisal edge of the most prominent upper central incisor.
is_1	Incision Superius 1	The anterior margin of the incisal edge of the most prominent upper central incisor.
is_2	Incision Superius 2	The posterior margin of the incisal edge of the most prominent upper

		central incisor.
li	Labrale Inferius	The most prominent point on the prolabium of the lower lip.
llt	Lower Lip Tangent Point	The upper tangent point of the tangent to the lower lip through sm_s
lnt	Lower Nasal Tangent Point	The upper tangent point of the nose-chin line.
ls	Labrale Superius	The most prominent point on the prolabium of the upper lip.
mms	Mesio-Molare Superius	The most infero-mesial point on the mesiobuccal cusp of the first upper molar.
n	Nasion	The most anterior point on the fronto-nasal suture.
n_s	Soft Tissue Nasion	The deepest point in the fronto-nasal curvature.
nst	Nasal Septum Tangent Point	The anterior tangent point of the tangent to the nasal septum through sn.
o	Orbitale	The deepest point on the infra-orbital margin.
p	Porion	The most superior point on the margin of the bony external auditory meatus.
pg	Pogonion	The most anterior point on the mandibular symphysis.
pgn	Prognathion	The point on the mandibular

		symphysis furthest from cd.
pgn_s	Soft Tissue Prognathion	The soft tissue point overlying pgn.
pg_s	Soft Tissue Pogonion	The most prominent point on the chin.
pm	Pterygomaxillare	The intersection between the nasal floor and the posterior contour of the maxilla.
pr	Prosthion	The most antero-inferior point on the upper alveolar margin.
prn	Pronasale	The most prominent point on the apex of the nose.
rli	Ramus Line Inferius	The lower tangent point of RL.
rls	Ramus Line Superius	The upper tangent point of RL.
s	Sella	The centre of the sella turcica. The upper limit of the sella turcica is defined as the line joining the tuberculum and dorsum sellae.
sm	Supramentale	The most posterior point on the anterior contour of the lower alveolar process.
sme	Submentale	The deepest point in the submental-neck curvature.
sm_s	Soft Tissue Supramentale	The deepest point in the mento-labial sulcus.
sn	Subnasale	The deepest point in the naso-labial curvature.

sp	Spinal Point	The apex of the anterior nasal spine.
ss	Subspinale	The most posterior point on the anterior contour of the upper alveolar process.
ss_s	Soft Tissue Subspinale	The most dorsal point on the upper lip overlying ss.
sto	Stomion	The deepest point in the rima oris.
tgo	Gonial Angle	The point of intersection between ML and RL
unt	Upper Nasal Tangent Point	The nasal tangent point of the nose-frontal line.

ii) Reference lines used in the study (Fig 19,21,22,23)

IL_i	Lower Incisal Line	The long axis of the lower central incisor measured from ai-ii.
IL_s	Upper Incisal Line	The long axis of the upper central incisor measured from as-is.
MBL	Mandibular Base Line	The line through pgn and cd.
ML	Mandibular Line	The tangent to the lower border of the mandible through gn.
NCL	Soft Tissue Nose-Chin Line	A line through lnt and ct.
NFL	Soft Tissue Nose-Frontal Line	A line through ft and unt
NL	Nasal Line	The maxillary plane. The line through sp and pm.

NSL	Nasion-Sella Line	The line through n and s.
ob	Overbite	A linear measurement of the distance the upper central incisor overlaps the most prominent lower central incisor, measured from ii to lnt.
oj	Overjet	A linear measurement of the protusion of the upper central incisor, measured from is to lnt.
OL_s	Occlusal Line Superius	A line through is and mms.
RL	Ramus Line	The tangent to the posterior border of the mandible.

iii) Radiographic cephalometric measurements.

a) Hard tissue linear dimensions.

1. n-s
2. n-sp
3. n-gn
4. s-ba
5. s-ar
6. s-pm
7. s-tgo
8. sp-gn
9. ar-tgo
10. sp-pm
11. ss-pm
12. pgn-cd

13. pg-tgo

14. sp-is

15. ii-gn

b) Hard tissue angular dimensions

16. n-s-ba

17. n-s-ar

18. pm-s-ba

19. s-n-sp

20. s-n-ss

21. s-n-sm

22. s-n-pg

23. ss-n-sm

24. s-n-pg

25. NSL/NL

26. NSL/ML

27. NL/ML

28. NSL/MBL

29. ML/RL

c) Dentoalveolar relations

30. IL_s /NL

31. IL_i /ML

32. oj (mm)

33. ob (mm)

34. is_1-is_2 (mm)

35. ii_1-ii_2 (mm)

36. is-as (mm)

37. ii-ai (mm)

d) Soft tissues

38. n_s-sn_s

39. n_s-prn

40. lnt to n-ss

41. s-n_s-unt

42. sto to NL

43. s-n_s-ss_s

44. sn to lnt-ls

45. ls to NCL

46. sto to ML

47. s-n_s-sm_s

48. sm_s to li-pg_s

49. li to NCL

50. ss_s-n_s-sm_s

51. sto to OL_s

52. s-n_s-pg_s

53. NFL/NCL

iv) Descriptions of the cephalometric measurements

1. n-s NASION-SELLA. Length of the anterior cranial base.
2. n-sp NASION-SPINAL POINT. Upper anterior facial height.
3. n-gn NASION-GNATHION. Total face height.
4. s-ba SELLA-BASION. Length of the posterior cranial

base (clivus length).

5. s-ar — SELLA-ARTICULARE. Condylar position.

6. s-pm — SELLA-PTERYGOMAXILLARE. Upper posterior facial height.

7. s-tgo — SELLA-MANDIBULAR LINE/RAMUS LINE INTERSECTION. Total posterior facial height.

8. sp-gn — SPINAL POINT-GNATHION. Lower anterior facial height.

9. ar-tgo — ARTICULARE-MANDIBULAR LINE/RAMUS LINE INTERSECTION. Ramus length.

10. sp-pm — SPINAL POINT-PTERYGOMAXILLARE. Maxillary length.

11. ss-pm — SUBSPINALE-PTERYGOMAXILLARE. Maxillary length at the alveolar level.

12. pgn-cd — PROGNATHION-CONDYLION. Overall mandibular length.

13. pg-tgo — POGONION-MANDIBULAR LINE/RAMUS LINE INTERSECTION. Mandibular body length.

14. sp-is — SPINAL POINT-INCISION SUPERIUS. Linear distance cf the upper central incisor tip to the anterior limit of the maxillary plane (maxillary dentoalveolar height).

15. ii-gn — INCISION INFERIUS-GNATHION. Linear distance of the lower central incisor tip to the anterior limit of the mandibular plane (mandibular dentoalveolar height).

16. n-s-ba — NASION-SELLA-BASION. Angle of flexion of the cranial base.

17. n-s-ar — NASION-SELLA-ARTICULARE. Mandibular condyle position.

18. pm-s-ba — PTERYGOMAXILLARE-SELLA-BASION. Anteroposterior position of the posterior border of the maxilla.

19. s-n-sp — SELLA-NASION-SPINAL POINT. Maxillary prognathism

20. s-n-ss — SELLA-NASION-SUBSPINALE. Maxillary prognathism.

21. s-n-sm — SELLA-NASION-SUPRAMENTALE. Mandibular prognathism.

22. s-n-pg — SELLA-NASION POGONION. Mandibular prognathism.

23. ss-n-sm — SUBSPINALE-NASION-SUPRAMENTALE. Relative prognathism.

24. ss-n-pg — SUBSPINALE-NASION-POGONION. Relative mandibular prognathism.

25. NSL/NL — NASION-SELLA LINE/NASAL LINE. Angulation of the maxillary plane to the anterior cranial base.

26. NSL/ML — NASION-SELLA LINE/MANDIBULAR LINE. Angulation of the mandibular plane to the anterior cranial base.

27. NL/ML — NASAL LINE/MANDIBULAR LINE. Angulation of the maxillary plane to the mandibular plane.

28. NSL/MBL — NASION-SELLA LINE/MANDIBULAR BASE LINE. Angulation of the mandibular base to the anterior cranial base.

29. ML/RL — MANDIBULAR LINE/RAMUS LINE. Gonial angle.

30. IL_s/NL — UPPER INCISOR LINE/NASAL LINE. Angulation of the upper central incisor to the maxillary plane.

31. IL_i/ML — LOWER INCISOR LINE/MANDIBULAR LINE. Angulation of the lower central incisor to the mandibular plane.

32. oj — OVERJET. Horizontal relationship of the upper and lower central incisors.

33. ob — OVERBITE. Vertical relationship of the upper and

lower central incisors.

34. is_1-is_2 INCISION SUPERIUS$_1$-INCISION SUPERIUS$_2$. Labio-palatal width of the upper central incisal edge.

35. ii_1-ii_2 INCISION INFERIUS$_1$-INSICION INFERIUS$_2$. Labio-lingual width of the lower central incisal edge.

36. is-as INCISION SUPERIUS-APEX SUPERIUS. Upper central incisor length.

37. ii-ai INCISION INFERIUS-APEX INFERIUS. Lower central incisor length.

38. n_s-sn_s SOFT TISSUE NASION-SUBNASALE. Height of nose.

39. n_s-prn SOFT TISSUE NASION-PRONASALE. Length of dorsum of nose.

40. lnt to n-ss LOWER NASAL TANGENT to NASION-SUBSPINALE. Nasal protusion.

41. s-n_s-unt SELLA-SOFT TISSUE NASION-UPPER NASAL TANGENT. Nasal vertical position (angular dimension).

42. sto to NL STOMION to NASAL LINE. Upper lip height.

43. s-n_s-ss_s SELLA-SOFT TISSUE-NASION-SOFT TISSUE SUBSPINALE. Upper lip protusion.

44. sn to lnt-ls SUBNASALE to LOWER NASAL TANGENT-LABRALE SUPERIUS. Depth of naso-labial curvature.

45. ls to NCL LABRALE SUPERIUS to NOSE-CHIN LINE. Upper lip prominence.

46. sto to ML STOMION to MANDIBULAR LINE. Lower lip height.

47. s-n_s-sm_s SELLA-SOFT TISSUE NASION-SOFT TISSUE SUPRAMENTALE. Lower lip protusion.

48. sm_s to li-pg_s SOFT TISSUE SUPRAMENTALE to LABRALE INFERIUS-SOFT TISSUE POGONION. Depth of labiomental fold.

49. li to NCL — LABRALE INFERIUS to NOSE-CHIN LINE. Lower lip prominence.

50. ss_s-n_s-sm_s — SOFT TISSUE SUBSPINALE-SOFT TISSUE NASION-SOFT TISSUE SUPRAMENTALE. Saggital soft tissue lip relationship.

51. sto to OL_s — STOMION to UPPER OCCLUSAL LINE. Lip contact position.

52. s-n_s-pg_s — SELLA-SOFT TISSUE-NASION-SOFT TISSUE POGONION. Soft tissue chin protusion.

53. NFL/NCL — NOSE-FRONTAL LINE/NOSE-CHIN LINE. Angular measurement of profile form.

FIGURE 18. Craniofacial reference points located on the lateral cephalometric radiograph.

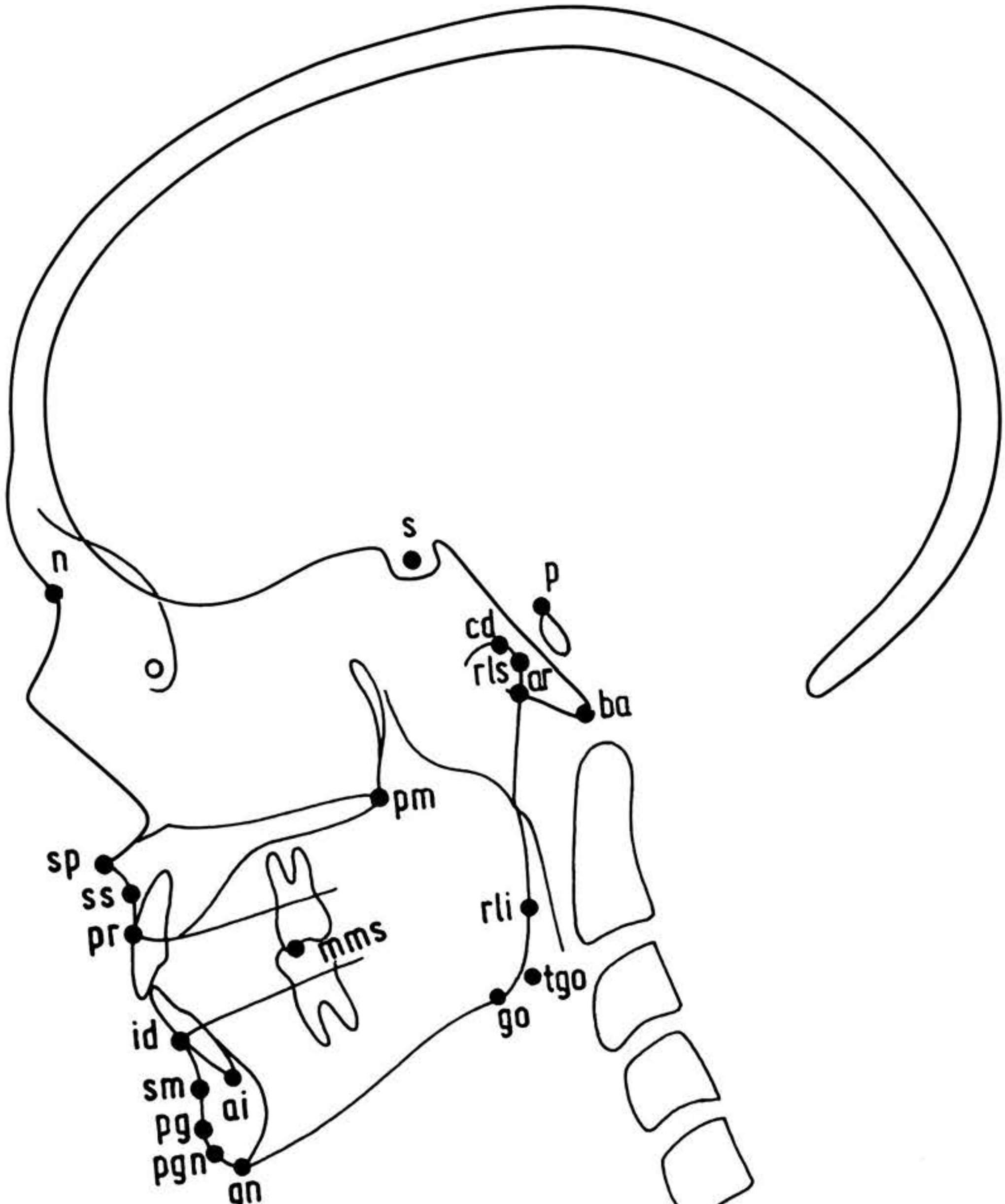

s
n
p
cd
rls
ar
ba
pm
sp
ss
pr
mms
rli
tgo
go
id
sm
ai
pg
pgn
gn

FIGURE 19. Incisal reference points and planes located on the lateral cephalometric radiograph.

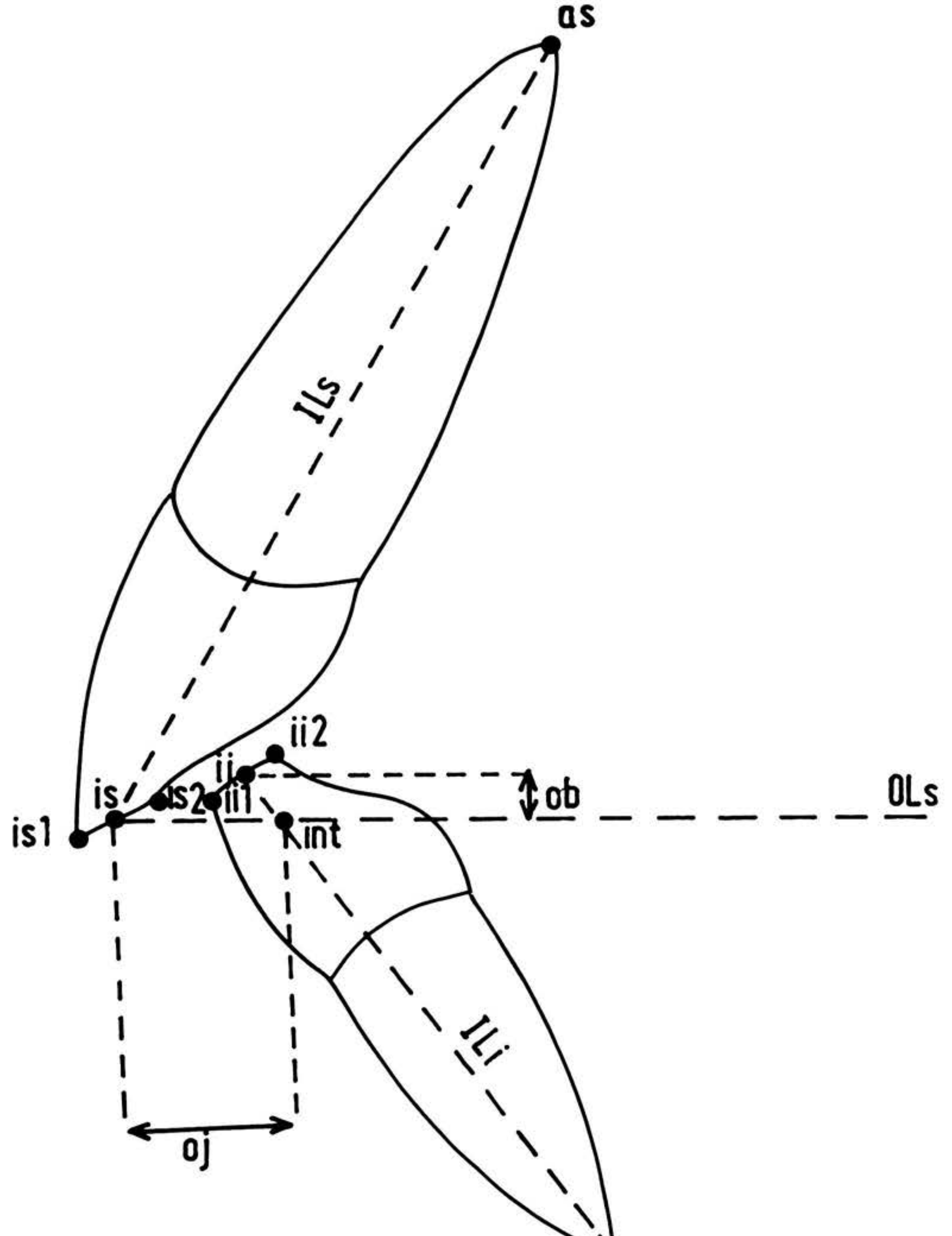

as
ILs
ii2
ii
ob
OLs
is
is2
ii1
is1
int
ILi
oj
ai

FIGURE 20. Soft tissue reference points located on the lateral cephalometric radiograph.

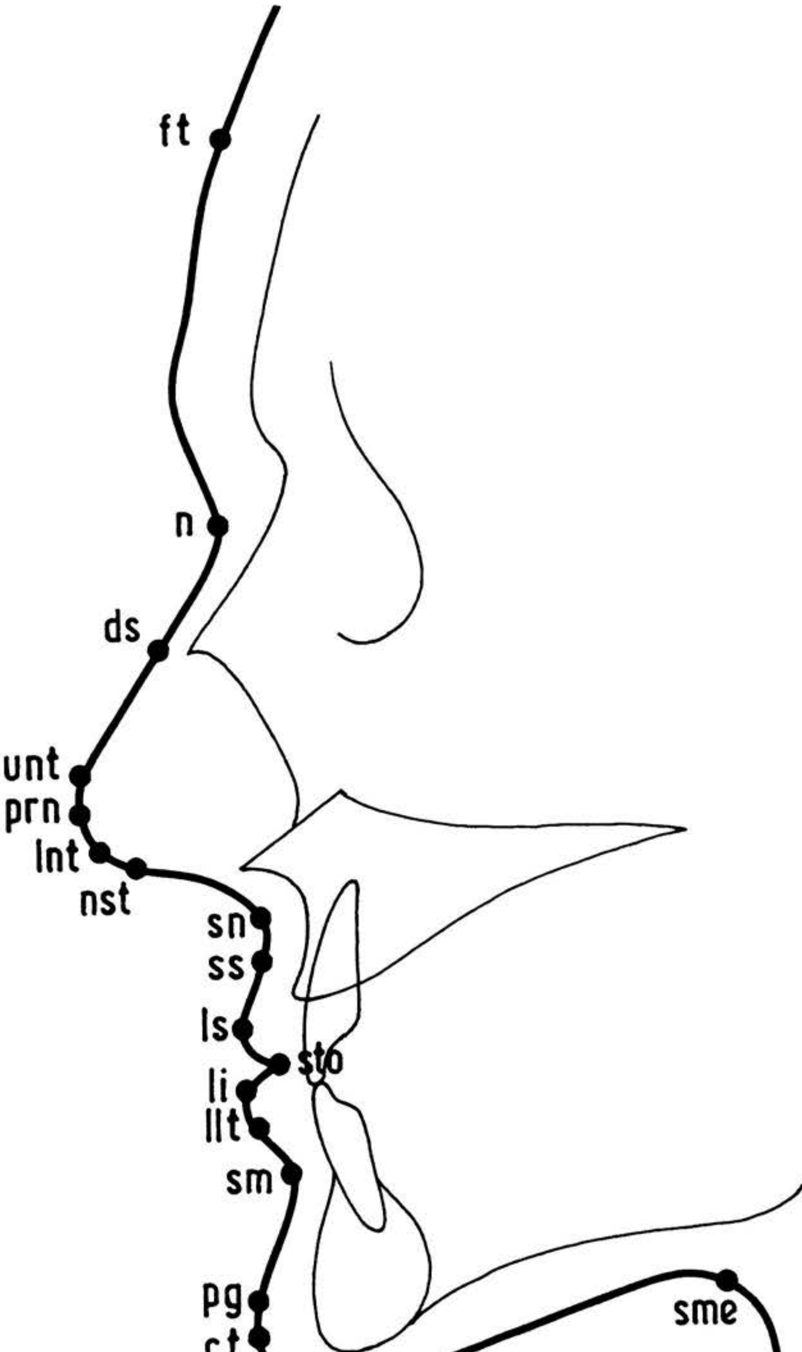

ft
n
ds
unt
prn
lnt
nst
sn
ss
ls
sto
li
llt
sm
pg
ct
pgn
gn
sme

FIGURE 21. Craniofacial reference lines located on the lateral cephalometric radiograph (1).

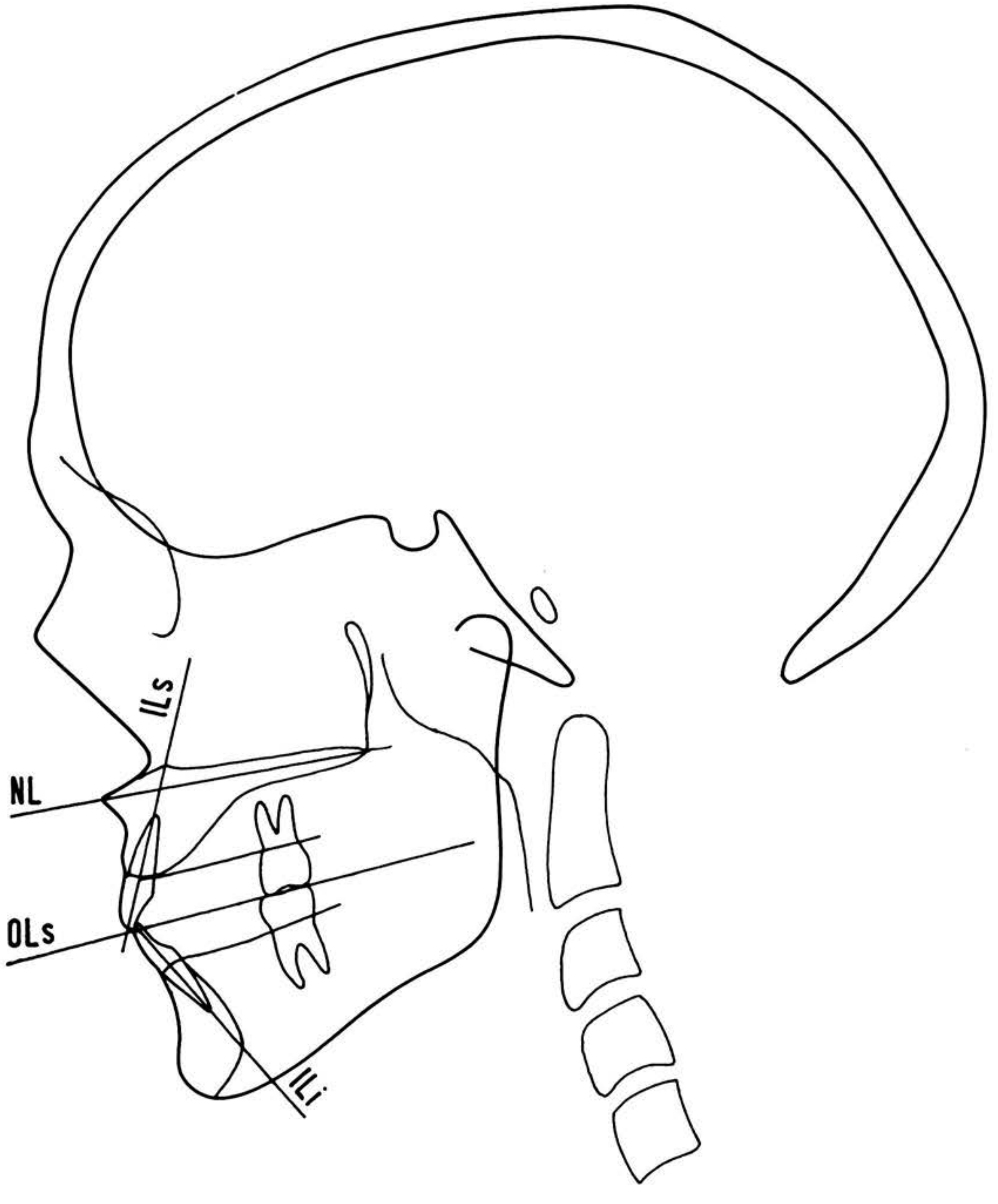
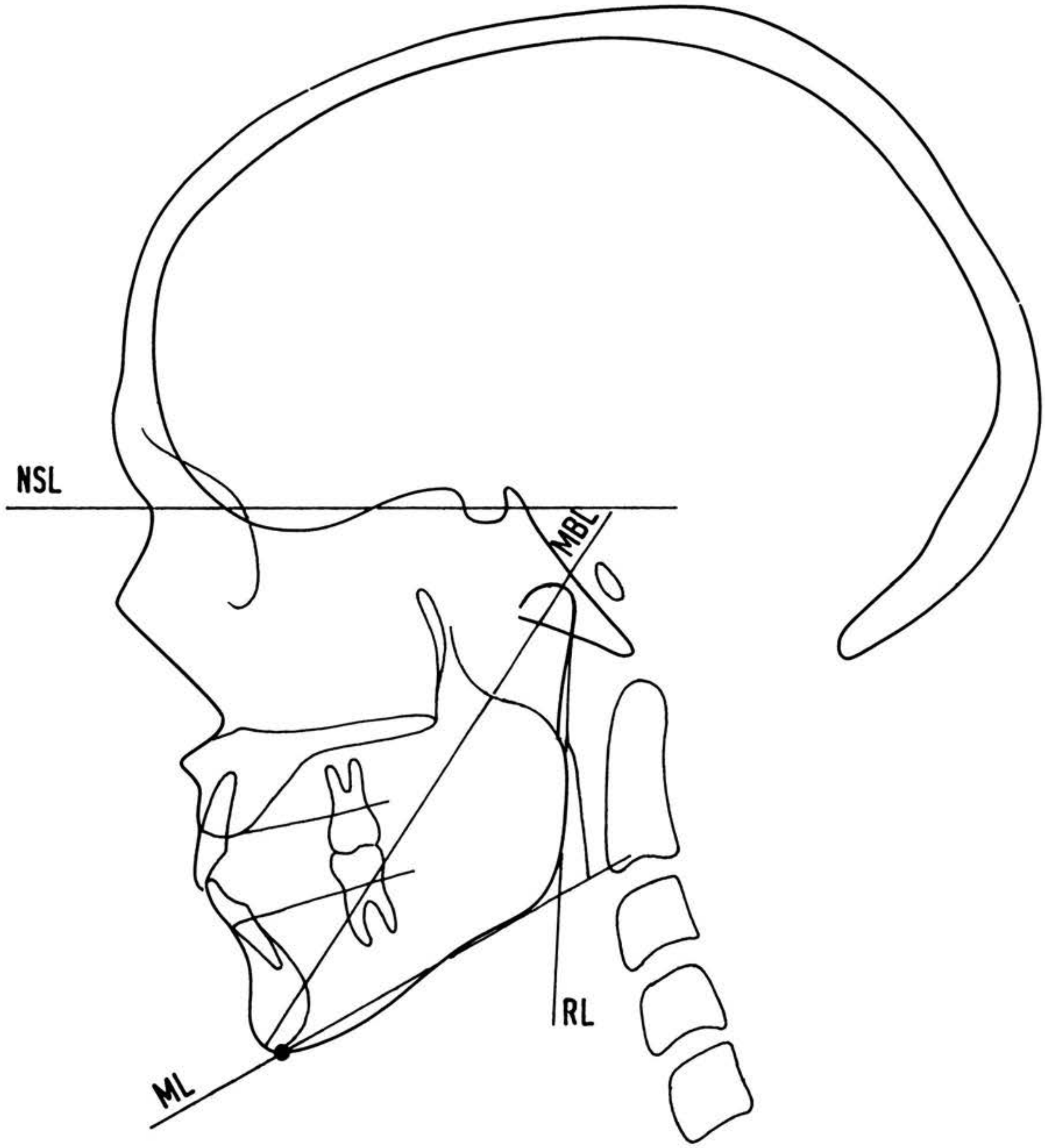
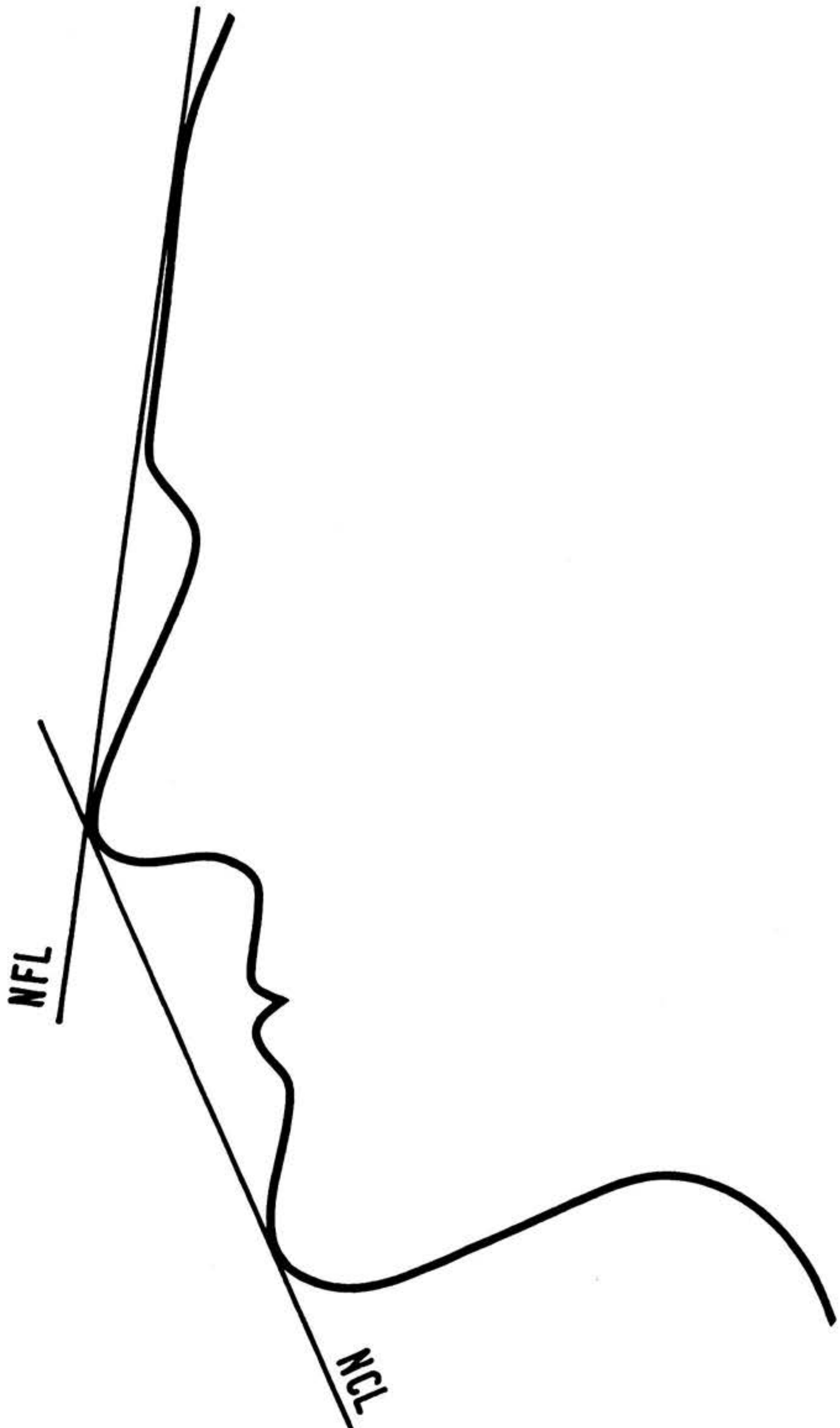

ILs
NL
OLs
ILi

FIGURE 22. Craniofacial reference lines located on the lateral cephalometric radiograph (2).



NSL
MBL
RL
ML

FIGURE 23. Soft tissue reference lines located on the lateral cephalometric radiograph.


NFL
NCL

C. Statistical Parameters

For analysis of the data, the following formulae were used:-

$\bar{x}$	arithmetical mean	$\frac{\Sigma x}{N}$
s	standard deviation	$\sqrt{\frac{\Sigma(x - \bar{x})^2}{N - 1}}$
S^2	variance	$\frac{\Sigma(x - \bar{x})^2}{N - 1}$
$s(\bar{x})$	standard error of the mean	$\frac{s}{\sqrt{N}}$
$\sqrt{b1}$	skewness	$\sqrt{\frac{N[\Sigma(x - \bar{x})^3]^2}{[\Sigma(x - x)^2]^3}}$
b2	kurtosis	$\frac{N\Sigma(x - \bar{x})^4}{[\Sigma(x - x)^2]^2}$
F	variance ratio	$\frac{s^2 \text{ max.}}{s^2 \text{ min.}}$

t student t test

1) $$\frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\left(\frac{1}{N_1} + \frac{1}{N_2}\right) \frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2}}}$$

2) $$\frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}}$$

S(i) Method error (Hald 1960)

$$\sqrt{\frac{\Sigma (x_1 - x_2)^2}{2N}}$$

r correlation coefficient

$$\frac{\sum(x - \bar{x}) \sum(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

CHAPTER 5

METHOD ERROR TESTS

A. DIGITISER VARIABLES.

In order to determine the error inherent in the equipment used in the study, tests were employed to assess the method error introduced by the following machine variables.

1. The error due to reproducibility of the X and Y co-ordinates for a single point.
2. The linearity distortion over the active field of the digitiser.

1. Error of the method for reproducibility of a single point by the digitiser.

This error test was carried out in order to determine the reproducibility of the point co-ordinates located by the cursor within the active field of the digitiser. A pen plot of a tracing recorded from a lateral cephalometric radiograph was obtained from a pool of data normally used for undergraduate teaching purposes and placed within the active area. This area on the digitiser screen was previously identified by moving the cursor across the screen and marking the limits of the active field as determined by the warning buzzer on the unit. Once the tracing was located entirely within the delineated area, it was secured in place with adhesive tape.

Twenty six fine points were identified on the plot corresponding to defined radiographic landmarks on the cephalometric radiograph. The cursor was placed over each point in turn and the X and Y co-ordinates written to a computer disk file with the help of a programme written for a previous study (Sandham 1987). The procedure was then repeated and a method error for the duplicate determination was calculated using the Hald statistic (Hald 1960).

Results

The first and second recordings of the X co-ordinate are shown in table 8. The values for the Y co-ordinates are similarly shown in table 9.

The means, standard deviations, standard errors, method errors and values for 't' were calculated for the differences between the first and second values for the X and Y co-ordinates.

The error of the method for digitiser reproducibility of a single point was 0.0156cm (0.156mm) for the X-axis and 0.0201cm (0.201mm) for the Y-axis.

2. **The linearity distortion over the active field of the digitiser.**
Linearity distortion may occur over the active field of the digitiser due to machine error. In order to accurately assess this, the pen plot tracing was moved within the active area of the digitiser and measurements obtained at each location. Re-recording of the X and Y co-ordinates for the twenty six points allowed for

Table 8

Method error test for single point reproducibility by the digitiser X-co-ordinates (cm)

Point	1st Value	2nd Value	Difference
1 Vertical	n = 24	n = 24	n = 24
2 Axis Pts.			
3	-12.00	-11.96	-0.04
4	- 4.60	- 4.60	-0.00
5	- 1.15	- 1.15	-0.00
6	- 2.53	- 2.51	-0.02
7	-11.10	-11.08	-0.02
8	- 9.94	- 9.93	-0.01
9	-10.99	-10.97	-0.02
10	-10.21	-10.19	-0.02
11	- 9.96	-10.00	-0.04
12	- 9.88	- 9.86	-0.02
13	- 9.50	- 9.49	-0.01
14	- 8.64	- 8.63	-0.01
15	- 9.16	- 9.14	-0.02
16	- 8.18	- 8.15	-0.03
17	- 7.78	- 7.77	-0.01
18	- 2.38	- 2.38	-0.00
19	- 3.23	- 3.23	-0.00
20	-13.92	-13.90	-0.02
21	-12.32	-12.29	-0.03
22	-11.39	-11.36	-0.03
23	-10.78	-10.75	-0.03
24	-10.75	-10.73	-0.02
25	-10.92	-10.90	-0.02
26	- 5.62	- 5.59	-0.03
	$\bar{X}$ = 8.620	$\bar{X}$ = 8.610	$\bar{X}$ = -0.0150
	SD = 3.507	SD = 3.500	SD = 0.0160
			SE = 0.003
			s(i) = 0.0156cm
			t = 0.01(n.s.)

Table 9

Method error test for single point reproducibility by the digitiser Y-co-ordinates (cm)

Point	1st Value	2nd Value	Difference
1 Vertical	n = 24	n = 24	n = 24
2 Axis Pts.			
3	11.98	11.91	0.07
4	12.86	12.85	0.01
5	9.33	9.33	0.00
6	9.64	9.63	0.01
7	6.58	6.56	0.02
8	6.52	6.51	0.01
9	3.80	3.78	0.02
10	4.39	4.38	0.01
11	4.02	3.96	0.06
12	3.05	3.02	0.03
13	2.21	2.21	0.00
14	2.12	2.12	0.00
15	0.74	0.72	0.02
16	0.65	0.63	0.02
17	5.00	4.99	0.01
18	5.88	5.90	-0.02
19	4.28	4.27	0.01
20	6.85	6.82	0.03
21	3.98	3.94	0.04
22	3.02	2.99	0.03
23	0.88	0.86	0.02
24	6.04	6.00	0.04
25	5.12	5.08	0.04
26	7.23	7.21	0.02
	$\bar{X}$ = 5.257	$\bar{X}$ = 5.236	$\bar{X}$ = 0.021
	SD = 3.273	SD = 3.271	SD = 0.020
			SE = 0.004
			s(i) = 0.0201cm
			t = 0.02(n.s.)

calculation of the line lengths between the following ten point sets.

Point 3 - 4
4 - 5
7 - 26
8 - 9
10 - 14
20 - 23
21 - 22
16 - 19
18 - 6
12 - 13

Twenty recordings of each set of points were made, each at varying positions within the active field of the digitiser. This enabled the calculation of the line lengths between each of the ten point sets at twenty different positions within this area.

The mean line lengths were calculated together with the standard deviations and standard errors. In order to determine the method error the twenty recordings were paired and the differences calculated. The paired sets are listed as follows.

Recording 1 - 2
3 - 4
5 - 6
7 - 8

9 - 10

11 - 12

13 - 14

15 - 16

17 - 18

19 - 20

The actual length of each linear dimension (mm) was measured using steel calipers with a vernier guage to two decimal places (Fig 24).

The linearity distortion occurring for each position of the plot within the active field is representative of the true machine error, as the resulting value is made up of twice the point placement error (as the line is drawn between the two points) plus any error due to linear distortion.

Results

The results for the twenty sets of recordings for the ten line lengths are shown in table 10 together with the mean line lengths, standard deviation, standard errors and method errors. The actual line lengths as measured using steel calipers are also shown to the nearest .01mm. Table 11 shows the differences between the paired recordings allowing for the calculation of the method errors.

Examination of the data thus obtained showed that in no case was the location error more than 0.5mm between the acutal length and the mean digitised dimension.

FIGURE 24. Steel calipers with vernier guage.

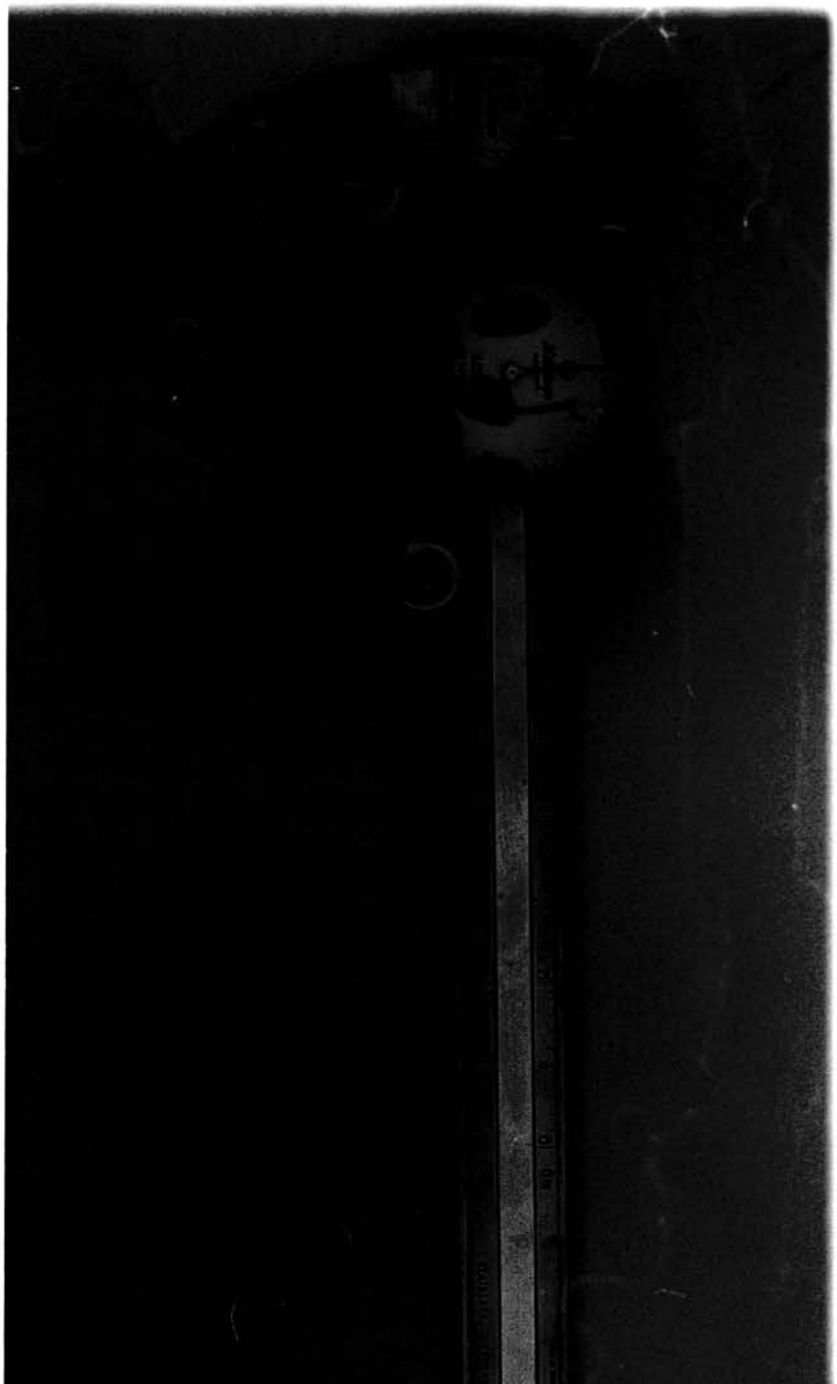


Table 10

Line length between points in the active field of the digitiser (mm)

	Point 3 - 4	Point 4 - 5	Point 7 - 26	Point 8 - 9	Point 10 - 14
1	74.3	49.0	55.6	29.0	27.4
2	74.4	49.4	55.5	28.8	28.1
3	74.0	49.8	55.4	28.8	27.6
4	74.4	48.9	55.3	28.9	27.9
5	74.1	49.3	55.6	28.9	27.2
6	74.5	49.2	55.2	28.9	27.5
7	74.2	49.5	55.5	28.8	27.7
8	74.6	49.3	55.3	28.6	27.8
9	74.4	49.6	55.5	28.7	27.7
10	74.3	49.4	55.7	29.0	27.8
11	74.1	49.6	55.7	29.4	27.6
12	74.3	49.7	55.8	29.2	27.7
13	74.2	49.1	55.7	28.8	27.9
14	74.2	49.4	55.6	29.0	27.6
15	73.9	48.9	55.4	28.6	27.5
16	74.2	49.3	55.3	29.2	28.0
17	74.1	49.3	55.4	28.7	28.1
18	74.1	49.1	55.6	28.6	28.0
19	73.9	48.9	55.4	28.9	27.5
20	74.1	49.0	55.4	28.7	27.6
Mean	74.22	49.29	55.50	28.88	27.71
S.D.	0.187	0.272	0.164	0.215	0.241
S.E.	0.042	0.061	0.037	0.048	0.054
S(i)	0.187	0.262	0.138	0.183	0.230
Actual length	74.33	49.35	55.48	28.38	27.56

Table 10 (continued)

Line length between points in the active field of the digitiser (mm)

	Point 20 - 23	Point 21 - 22	Point 16 - 19	Point 18 - 6	Point 12 - 13
1	67.1	13.0	61.4	37.3	8.7
2	67.3	13.0	61.4	37.6	9.1
3	67.2	13.4	61.2	37.4	8.8
4	67.0	13.0	61.6	37.4	8.7
5	67.0	13.0	61.5	37.6	8.8
6	67.2	13.2	62.0	37.4	8.6
7	67.0	13.4	61.2	37.5	8.8
8	67.3	13.3	61.7	37.1	8.8
9	67.2	13.7	61.6	36.9	9.0
10	67.5	12.9	61.2	37.2	8.8
11	67.4	13.4	61.2	37.0	8.8
12	67.3	13.2	61.4	37.2	8.7
13	67.1	13.2	61.4	37.3	8.9
14	66.7	13.3	61.3	37.2	8.8
15	67.2	13.4	61.8	37.6	9.0
16	66.8	13.2	61.1	37.4	8.8
17	67.7	12.9	61.5	37.3	9.0
18	67.3	12.8	61.0	37.5	9.2
19	67.1	13.0	61.7	37.5	9.1
20	66.8	13.2	61.3	37.3	9.0
Mean	67.16	13.18	61.43	37.34	8.84
S.D.	0.242	0.224	0.253	0.195	0.246
S.E.	0.054	0.050	0.057	0.044	0.055
S(i)	0.290	0.222	0.305	0.166	0.135
Actual length	67.00	13.45	61.35	37.24	8.96

Table 11

Line lengths between points in the active field of the digitiser.
Calculation of Method Error - Differences between paired values (mm).

Paired Values	Point 3 - 4	Point 4 - 5	Point 7 - 26	Point 8 - 9	Point 10 - 14	Point 20 - 23	Point 21 - 22	Point 16 - 19	Point 18 - 6	Point 12 - 13
1 - 2	-0.2	-0.4	0.1	-0.2	-0.7	-0.2	0.0	0.0	-0.3	-0.4
3 - 4	-0.4	0.9	0.1	-0.1	-0.7	0.2	0.4	-0.4	0.0	0.1
5 - 6	-0.4	0.1	0.4	0.0	-0.3	-0.2	-0.2	0.5	0.2	0.2
7 - 8	-0.4	0.2	0.2	0.2	-0.3	-0.3	0.1	-0.5	0.4	0.0
9 - 10	-0.1	0.2	-0.3	-0.3	-0.1	-0.3	0.8	0.4	-0.3	0.2
11 - 12	-0.2	-0.1	-0.1	0.2	-0.1	0.1	0.2	-0.2	-0.2	0.1
13 - 14	0.0	-0.3	-0.1	-0.2	0.3	-0.6	-0.1	0.1	0.1	0.1
15 - 16	-0.3	-0.4	0.1	-0.6	-0.5	-0.6	0.2	0.7	0.2	0.2
17 - 18	0.0	0.2	-0.2	0.1	0.1	-0.4	0.1	0.5	-0.2	-0.2
19 - 20	-0.2	-0.1	0.0	0.2	-0.1	-0.7	-0.2	0.5	0.2	0.1
$\bar{X}$ =	-0.22	0.03	0.02	-0.07	-0.18	-0.22	0.13	0.16	0.01	0.04
S.D.=	0.155	0.389	0.204	0.263	0.286	0.365	0.302	0.422	0.247	0.196
S(i)=	0.187	0.262	0.138	0.183	0.230	0.290	0.222	0.305	0.166	0.135

B. CEPHALOMETRIC VARIABLES.

In order to determine the total error of the method for point placement by the operator together with the error inherent in point location by the digitiser, 14 subjects (N=14) selected from the control group (N=40) had 53 cephalometric points determined on a lateral skull radiograph. This group consisted of young adults (mean age 26.1 years) selected at random from the total control group (N=40). The defined points were then transferred to acetate tracing paper and digitised. The process was repeated the following day for the same 14 subjects in order to compare the measurements of linear and angular cephalometric variables obtained.

In both cases the X and Y co-ordinate values were written to computer disk files with the aid of the computer programme modified for use in the study. The first digitisation was written to a computer file named "Meth A" and the second digitisation written to a file named "Meth B".

Statistical analysis of 53 variables of craniofacial form was carried out on the two files using the facilities of the Edinburgh University Computing Service (EUCS).

The computer programme used in this study enabled digitised co-ordinate data to be recorded in numeric sequence, with an audible signal generated to indicate a point has been recorded. Once digitising of the acetate tracing was complete, a plot of skeletal and soft tissue profile was generated using the computer programme.

Inspection of the pen plot obtained was carried out to confirm that all points had been correctly digitised.

In order to further check the accuracy of point placement during digitisation, the statistical parameters of skewness ($\sqrt{b1}$) and kurtosis (b2) were used to analyse the data. Any digitisation error is reflected as a gross distribution error from a mean value which enables the rapid identification of such errors by scrutiny of skewness and kurtosis values. The measure of kurtosis (b2) describes the degree of peak of the distribution of a sample. In a sample of normal distribution, the value of kurtosis has a mean of 3 (RAO 1952). Lower values indicate platykurtosis, or a flattened distribution curve, whereas higher values indicate leptokurtosis, with a sharper peak to the distribution curve.

The measure of skewness ($\sqrt{b1}$) describes the symmetry of the distribution curve, and where the samples are derived from a normal distribution, the mean of skewness is zero (Pearson 1931).

Scrutiny of the results of skewness and kurtosis values enabled digitising errors to be detected as any gross errors are reflected in the distributions and revealed by these values of b1 and b2 Tables (12,13).

Results

The linear and angular dimensions for the 53 variables used for the cephalometric analysis of the 14 subjects from the control group are shown in table 12. The results of the same dimensions from the second recording are shown on table 13. Analyses of the differences between the two recordings are tabulated in table 14.

The parameters used are the mean ($\bar{x}$), standard error of the mean ($s(\bar{x})$), standard deviation (s), variance (s^2), skewness ($\sqrt{b1}$), kurtosis ($b2$) and in the analysis of the differences between the first and second recordings, the method error ($s(i)$) was calculated. Initial examination of the values of $\sqrt{b1}$ and $b2$ revealed only one distribution error due to incorrect point placement on one of the radiographs during the second recording. Once this was identified, the point was corrected and the statistical parameters recalculated.

The 53 cephalometeric points used in the study could thus be reproduced with only a small method error ranging from 0.038mm (pg-tgo) to 0.907mm (oj) for the linear measurements, and from 0.019° (s-n-sm) to 3.118° (sto to OLS) for the angular dimensions.

Table 12

Method A

Control Group (14 Subjects only) - First Digitisation

Variable (N = 14)	NR	Range Min.	Range Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
n-s	1	72.4	85.2	78.407	1.072	4.013	16.102	0.305	-1.109
n-sp	2	54.4	66.7	59.057	0.898	3.412	11.296	0.611	0.828
n-gn	3	121.8	139.9	132.764	1.588	5.828	33.966	-0.477	-0.753
s-ba	4	45.9	61.2	52.086	1.393	5.210	27.147	0.685	-1.119
s-ar	5	35.2	52.6	40.607	1.254	4.692	22.018	1.248	2.106
s-pm	6	47.0	59.8	53.064	0.831	3.109	9.666	0.291	0.968
s-tgo	7	76.0	103.5	90.414	2.346	8.779	77.078	-0.263	-0.889
sp-gn	8	65.5	90.7	75.693	1.765	6.605	43.622	0.863	-0.769
ar-tgo	9	46.0	66.0	54.586	1.499	5.610	31.471	0.081	-0.055
sp-pm	10	51.6	68.1	61.079	1.447	5.416	29.328	-0.103	-0.181
ss-pm	11	48.0	60.5	54.193	0.964	3.605	12.999	0.515	-0.347
pgn-cd	12	114.9	144.5	127.050	1.997	7.471	55.823	0.793	1.228
pg-tgo	13	70.7	95.4	84.471	1.803	6.746	45.513	-0.357	-0.279

linear dimensions mm
angular dimensions degrees

Table 12 (Continued)

Method A

Control Group (14 Subjects only) - First Digitisation

Variable (N = 14)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
sp-is	14	26.8	39.6	33.264	0.976	3.652	13.339	0.161	-0.296
ii-gn	15	42.5	53.2	46.921	0.780	2.920	8.525	0.536	0.265
n-s-ba	16	121.4	140.2	133.514	1.466	5.484	30.075	-0.633	0.083
n-s-ar	17	118.0	130.7	124.321	1.029	3.849	14.813	0.153	-1.069
pm-s-ba	18	47.9	70.1	60.366	1.525	5.704	32.538	-0.424	0.762
s-n-sp	19	79.1	96.4	87.429	1.264	4.729	22.367	0.262	-0.155
s-n-ss	20	76.5	85.8	80.614	0.738	2.760	7.618	0.272	-0.237
s-n-sm	21	71.7	83.4	77.636	0.861	3.221	10.372	0.323	0.331
s-n-pg	22	73.7	87.5	79.829	0.935	3.497	12.227	0.599	0.737
ss-n-sm	23	0.7	8.0	4.164	0.516	1.930	3.724	-0.098	0.471
ss-n-pg	24	1.1	8.0	3.521	0.520	1.944	3.780	1.332	1.524
NSL/NL	25	1.2	18.4	7.764	1.191	4.456	19.858	0.834	1.388
NSL/ML	26	21.9	45.1	32.979	1.703	6.371	40.596	0.040	-0.090
NL/ML	27	15.0	35.2	25.221	1.485	5.557	30.885	-0.148	-0.120
NSL/MBL	28	45.3	60.4	54.429	1.161	4.343	18.859	-0.394	-0.018
ML/RL	29	114.0	139.6	125.793	2.285	8.549	73.085	0.066	-1.081
IL_s/NL	30	95.1	117.3	106.936	1.876	7.018	49.250	-0.045	-1.072
ILi/ML	31	74.1	107.7	88.314	2.422	9.064	82.149	0.575	0.036

Table 12 (Continued)

Method A
Control Group (14 Subjects only) - First Digitisation

Variable (N = 14)	NR	Range Min.	Range Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
oj	32	- 6.6	8.7	5.571	0.658	2.462	6.062	-1.332	1.994
ob	33	-10.2	- 0.2	- 4.443	0.685	2.561	6.561	-0.839	1.022
$is_1 is_2$	34	0.0	3.0	1.271	0.312	1.169	1.367	-0.081	-1.917
$ii_1 - ii_2$	35	0.0	3.7	0.693	0.322	1.203	1.448	1.602	1.656
is-as	36	25.1	34.0	29.06	0.682	2.553	6.519	0.191	2.04
ii-ai	37	20.3	28.9	26.15	0.620	2.321	5.389	1.049	3.23
$n_s - sn_s$	38	52.6	71.9	63.929	1.634	6.115	37.391	-0.410	-1.033
n_s-prn	39	44.7	62.4	55.186	0.522	5.694	32.424	-0.181	-1.194
lnt to n-ss	40	30.7	44.3	36.029	1.099	4.112	16.911	0.648	-0.663
s-n_s-unt	41	106.3	131.9	118.750	1.777	6.650	44.221	-0.062	0.177
sto to NL	42	23.9	37.7	29.600	1.072	4.012	16.094	0.584	-0.332
s-n_s-ss_s	43	84.7	98.1	91.471	1.051	3.933	15.467	0.122	-0.581
sn to lnt-ls	44	5.4	10.1	8.221	0.413	1.544	2.383	0.675	-0.764
ls to NCL	45	3.1	13.1	7.179	0.708	2.647	7.008	0.581	0.549
sto to ML	46	41.7	58.9	48.443	1.125	4.209	17.712	0.994	1.877
s-n_s-sm_s	47	78.7	90.7	83.743	1.011	3.782	14.306	0.422	-1.025
sm_s to li-pg_s	48	3.7	9.1	6.429	0.460	1.721	2.962	0.084	-1.012
li to NCL	49	0.8	9.5	4.907	0.803	3.004	9.025	0.078	-1.203
ss_s-n_s-sm_s	50	3.0	11.4	7.757	0.597	2.233	4.986	0.562	0.170
sto to OLS	51	123.2	176.6	152.579	3.858	14.434	208.346	0.243	-0.135
s-n_s-pg_s	52	80.4	93.2	85.721	1.117	4.179	17.465	0.329	-1.213
NFL/NCL	53	-148.1	-131.8	-142.286	1.355	5.071	25.718	1.14	0.755

Table 13

Method B

Control Group (14 Subjects only) - Second Digitisation

Variable (N = 14)	NR	Range Min.	Range Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
n-s	1	73.1	85.8	78.736	1.052	3.935	15.484	0.389	-1.031
n-sp	2	53.3	66.6	59.007	0.912	3.411	11.633	0.466	0.859
n-gn	3	122.3	139.6	132.729	1.484	5.552	30.825	-0.496	-0.804
s-ba	4	46.1	61.5	52.143	1.396	5.223	27.278	0.737	-0.918
s-ar	5	34.4	52.4	40.521	1.268	4.745	22.511	1.116	1.809
s-pm	6	47.1	59.9	52.986	0.846	3.166	10.023	0.346	0.758
s-tgo	7	75.7	103.3	90.429	2.362	8.837	78.090	-0.345	-0.908
sp-gn	8	65.6	90.5	75.636	1.763	6.596	43.504	0.797	0.592
ar-tgo	9	45.4	66.0	54.557	1.554	5.813	33.795	0.012	-0.245
sp-pm	10	52.1	67.9	60.971	1.407	5.265	27.725	-0.031	-1.275
ss-pm	11	48.0	60.3	54.414	0.970	3.631	13.186	0.447	-0.449
pgn-cd	12	115.0	144.0	126.836	1.947	7.285	53.073	0.840	1.312
pg-tgo	13	70.7	93.6	84.457	1.705	6.378	40.680	-0.572	-0.063

linear dimensions mm
angular dimensions degrees

Table 13 (Continued)

Method B

Control Group (14 Subjects only) - Second Digitisation

Variable (N = 14)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
sp-is	14	26.3	39.6	33.150	0.991	3.706	13.738	0.087	-0.194
ii-gn	15	42.3	52.7	46.893	0.747	2.794	7.805	0.369	-0.021
n-s-ba	16	121.6	139.8	133.121	1.403	5.248	27.545	-0.566	0.078
n-s-ar	17	118.2	131.1	123.900	1.076	4.025	16.203	0.363	-1.164
pm-s-ba	18	47.9	69.1	60.229	1.493	5.588	31.224	-0.526	0.722
s-n-sp	19	78.9	97.2	87.207	1.262	4.720	22.282	0.185	0.403
s-n-ss	20	75.9	86.5	80.664	0.787	2.944	8.666	0.195	0.146
s-n-sm	21	71.8	83.0	77.643	0.847	3.169	10.040	0.129	-0.013
s-n-pg	22	73.4	87.1	79.793	0.914	3.420	11.695	0.398	0.762
ss-n-sm	23	1.1	7.6	4.071	0.475	1.778	3.162	0.009	0.274
ss-n-pg	24	1.2	7.1	3.436	0.475	1.778	3.162	1.019	0.611
NSL/NL	25	0.8	18.6	7.886	1.240	4.639	21.521	0.709	0.974
NSL/ML	26	22.5	45.1	32.943	1.701	6.365	40.520	0.194	-0.280
NL/ML	27	15.2	34.4	25.064	1.423	5.324	28.342	-0.166	-0.222
NSL/MBL	28	45.8	60.1	54.293	1.093	4.090	16.728	-0.379	-0.203
ML/RL	29	114.1	140.0	125.621	2.277	8.520	72.585	0.175	-1.020
ILs/NL	30	94.7	116.6	106.700	1.803	6.745	45.494	-0.108	-0.970
ILi/ML	31	74.4	107.5	88.336	2.369	8.862	78.542	0.561	0.083

Table 13 (Continued)

Method B
Control Group (14 Subjects only) - Second Digitisation

Variable (N = 14)	NR	Range Min.	Range Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
oj	32	- 1.4	8.6	5.229	0.721	2.696	7.270	-1.306	1.810
ob	33	- 9.8	0.1	- 4.286	0.682	2.552	6.515	-0.638	0.815
is_1-is_2	34	0.0	2.5	1.236	0.290	1.086	1.179	-0.209	-2.119
ii_1-ii_2	35	0.0	2.8	0.600	0.255	0.956	0.914	1.357	0.480
is-as	36	25.2	34.5	28.921	0.677	2.532	6.410	0.428	2.922
ii-ai	37	20.7	28.9	26.029	0.612	2.289	5.241	0.993	3.257
n_s-sn_s	38	52.0	71.4	63.864	1.605	6.006	36.076	-0.511	-0.761
n_s-prn	39	45.1	62.2	55.486	1.515	5.669	32.138	-0.207	-1.215
lnt to n-ss	40	29.7	43.3	35.750	1.111	4.156	17.272	0.411	-1.032
s-n_s-unt	41	106.4	133.4	118.564	1.813	6.784	46.018	0.250	0.738
sto to NL	42	23.7	37.6	29.714	1.086	4.063	16.506	0.501	-0.460
s-n_s-ss_s	43	84.6	99.2	91.229	1.087	4.069	16.553	0.479	0.038
sn to lnt-ls	44	5.7	10.3	8.271	0.397	1.484	2.204	-0.465	-0.992
ls to NCL	45	2.7	13.3	7.336	0.746	2.793	7.801	0.359	0.343
sto to ML	46	41.9	58.6	48.229	1.117	4.179	17.462	1.011	1.727
s-n_s-sm_s	47	78.6	90.0	83.493	1.001	3.747	14.038	0.478	-1.163
sm_s to li-pg_s	48	4.0	9.4	6.450	0.458	1.712	2.930	0.263	-1.075
li to NCL	49	0.5	9.8	5.079	0.790	2.956	8.739	0.025	-0.937
ss_s-n_s-sm_s	50	3.2	12.0	7.729	0.613	2.295	5.265	-0.307	0.276
sto to OLS	51	124.5	178.6	153.757	3.774	14.122	199.420	-0.200	0.219
s-n_s-pg_s	52	80.7	92.4	85.521	1.080	4.041	16.333	0.399	-1.336
NFL/NCL	53	-148.2	-131.9	-142.307	1.362	5.095	25.962	1.151	0.716

Table 14

Method A/Method B Differences

Distribution of the differences between the duplicate measurements

Variable (N = 14)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2	Method error s(i)
n-s	1	-0.90	0.20	-0.329	0.078	0.292	0.085	-0.190	-0.008	0.869
n-sp	2	-0.60	1.20	0.050	0.142	0.532	0.283	1.376	1.128	0.132
n-gn	3	-0.70	1.00	0.036	0.142	0.530	0.281	0.363	-0.617	0.094
s-ba	4	-0.60	0.70	-0.057	0.109	0.407	0.166	0.556	-0.976	0.151
s-ar	5	-1.00	0.80	0.086	0.115	0.431	0.186	-1.142	2.548	0.227
s-pm	6	-0.40	0.80	0.079	0.096	0.360	0.130	0.469	-0.298	0.208
s-tgo	7	-0.80	0.50	-0.014	0.097	0.361	0.131	-0.836	0.575	0.038
sp-gn	8	-0.90	1.00	0.057	0.143	0.536	0.287	-0.293	-0.249	0.151
ar-tgo	9	-0.50	0.60	0.029	0.092	0.343	0.118	0.064	-0.932	0.075
sp-pm	10	-1.00	0.70	0.107	0.135	0.505	0.255	-0.783	-0.037	0.283
ss-pm	11	-1.20	0.80	-0.221	0.136	0.510	0.260	0.109	0.284	0.586
pgn-cd	12	-0.40	0.60	0.214	0.080	0.301	0.091	-0.496	-0.639	0.567
pg-tgo	13	-0.70	1.80	0.014	0.174	0.650	0.423	1.620	3.649	0.038
sp-is	14	-0.30	0.50	0.114	0.064	0.238	0.057	-0.037	-0.841	0.302
ii-gn	15	-1.00	0.90	0.029	0.142	0.531	0.282	-0.164	-0.109	0.075

$$s(i) = \sqrt{\frac{\Sigma (d)^2}{2N}}$$

Table 14 (Continued)

Method A/Method B Differences

Variable (N = 14)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2	Method error s(i)
n-s-ba	16	-0.30	2.00	0.393	0.182	0.682	0.465	1.465	1.434	1.039
n-s-ar	17	-0.40	1.80	0.421	0.138	0.516	0.266	1.211	3.504	1.115
pm-s-ba	18	-0.50	1.00	0.107	0.102	0.383	0.147	0.950	1.137	0.283
s-n-sp	19	-1.10	1.30	0.221	0.188	0.703	0.494	-0.356	-0.275	0.586
s-n-ss	20	-0.70	0.60	-0.050	0.113	0.422	0.178	-0.287	-1.194	0.132
s-n-sm	21	-1.10	0.50	-0.007	0.115	0.430	0.185	-1.387	2.180	0.019
s-n-pg	22	-1.10	0.50	0.036	0.123	0.458	0.210	-1.465	1.940	0.094
ss-n-sm	23	-0.60	0.90	0.093	0.108	0.403	0.162	0.448	0.219	0.246
ss-n-pg	24	-0.50	0.90	0.086	0.095	0.355	0.126	0.571	0.877	0.227
NSL/NL	25	-0.80	0.70	-0.121	0.128	0.477	0.228	0.303	-0.868	0.321
NSL/ML	26	-0.60	0.80	0.036	0.123	0.460	0.212	0.351	-0.839	0.094
NL/ML	27	-0.70	0.80	0.157	0.139	0.521	0.272	-0.623	-0.742	0.416
NSL/MBL	28	-0.50	1.60	0.136	0.150	0.561	0.315	1.417	2.451	0.359
ML/RL	29	-0.40	1.20	0.171	0.137	0.514	0.264	0.876	-0.242	0.454
IL_s/NL	30	-0.90	1.60	0.236	0.187	0.700	0.490	0.171	-0.418	0.624
ILi/ML	31	-1.20	1.30	-0.021	0.192	0.719	0.517	0.370	-0.376	0.057
oj	32	-0.30	1.20	0.343	0.120	0.448	0.201	0.853	-0.313	0.907
ob	33	-0.80	0.20	-0.157	0.079	0.295	0.087	-0.533	-0.040	0.416
is_1-is_2	34	-0.40	0.50	0.036	0.063	0.234	0.055	0.042	0.358	0.094

Table 14 (Continued)

Method A/Method B Differences

Variable (N = 14)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2	Method error s(i)
ii_1-ii_2	35	-0.20	0.90	0.093	0.083	0.310	0.096	1.795	2.922	0.246
is-as	36	-0.50	1.00	0.136	0.113	0.422	0.178	0.243	2.369	0.303
ii-ai	37	-0.40	0.60	0.050	0.089	0.335	0.112	0.757	1.914	0.231
n_s-sn_s	38	-0.80	0.90	0.064	0.122	0.457	0.209	-0.024	-0.209	0.170
n_s-prn	39	-0.90	0.40	-0.300	0.117	0.437	0.191	0.427	-0.771	0.794
lnt to n-ss	40	-0.50	1.00	0.279	0.118	0.441	0.194	0.123	-0.409	0.737
s-n_s-unt	41	-1.50	1.50	0.186	0.214	0.801	0.641	-0.330	0.178	0.491
sto to NL	42	-1.20	0.20	-0.114	0.095	0.355	0.126	-1.875	2.775	0.302
s-n_s-ss_s	43	-1.10	1.70	0.243	0.199	0.746	0.556	0.170	0.166	0.643
sn to lnt-ls	44	-0.60	0.60	-0.050	0.096	0.359	0.129	0.140	-0.955	0.132
ls to NCL	45	-0.60	0.40	-0.157	0.080	0.298	0.089	0.490	-0.590	0.416
sto to ML	46	-0.90	1.70	0.214	0.166	0.620	0.384	0.659	1.800	0.567
s-n_s-sm_s	47	-0.50	1.00	0.250	0.139	0.520	0.270	0.015	-1.389	0.661
sm_s to li-pg_s	48	-0.60	0.80	-0.021	0.108	0.402	0.162	0.455	-0.098	0.057
li to NCL	49	-0.80	0.40	-0.171	0.096	0.358	0.128	-0.096	-0.909	0.453
ss_s-n_s-sm_s	50	-0.60	0.90	0.029	0.121	0.453	0.205	0.848	-0.183	0.076
sto to OLS	51	-5.10	3.10	-1.179	0.627	2.347	5.510	0.382	-0.278	3.118
s-n_s-pg_s	52	-0.50	0.80	0.200	0.115	0.431	0.186	-1.048	-0.302	0.529
NFL/NCL	53	-0.90	0.70	0.021	0.103	0.385	0.148	-0.682	1.744	0.057

CHAPTER 6

RESULTS

The results of the cephalometric analysis of the lateral skull radiographs of the control group are shown in table 15. The results of the cephalometric analysis of similar radiographs for the study sample are shown in table 16. In these tables the linear measurements are given in millimetres and the angular dimensions are expressed in degrees.

Tables 15 and 16, indicate the results obtained for 53 cephalometric linear and angular variables describing cranial base, maxillary, mandibular, dento-alveolar and soft tissue morphology for the control and sample categories.

Descriptive statistical data for the comparison between the control group and the study sample is shown on table 17. A summary of the statistical differences between the two categories and the differences between their mean values of linear and angular craniofacial variables is shown on table 20. The mean values of these variables were also used to create a mean plot for each group to enable overall visual comparison of the differences between the two groups (Fig 25, 26). Tables 18, 19 indicate the results obtained for the calculation of correlation coefficients describing the association of facial height with general aspects of craniofacial hard and soft tissue morphology. These results are summarised in tables 21 and 22.

COMPARISON OF THE CONTROL GROUP AND THE STUDY SAMPLE

The statistical data for this comparison is shown on table 17. Many statistically significant differences were recorded for the 53 linear and angular variables describing skeletal and soft tissue form.

A. CRANIAL BASE

Few significant differences were found in cranial base structures on comparison of the control and sample categories. No significant difference was found in the angle of flexion of the cranial base (n-s-ba) in the study sample when compared to controls (p=0.686). Similarly, there was no significant difference in the linear dimension of the posterior cranial base (s-ba) in the study sample when comparisons were made with the control category (p=0.307).

The mean value of anterior cranial base length (n-s) was however, significantly greater in the study sample (p=0.005). The mean value of this dimension was 3.05mm larger than that of the control category, indicating a more anterior positioning of nasion in the study sample when compared with controls.

B. TOTAL FACIAL HEIGHT

No significant difference was found in total anterior facial height (n-gn) between the study sample and control group (p=0.756). However, total posterior facial height (s-tgo) was found to be significantly greater in the study sample (p=0.009), the value of the difference between the means of the control and sample categories being 4.91mm.

C. UPPER FACIAL HEIGHT

Upper anterior facial height (n-sp) was found to be significantly greater in the study sample when comparisons were made with controls (p=0.016). The mean value of upper posterior facial height (s-pm) was also found to be significantly greater in the sample category than the value for this variable in the control group (p=0.016). The mean linear dimension for upper anterior facial height (n-sp) and upper posterior facial height (s-pm) were recorded as 2.37mm and 2.36mm respectively greater in the sample category than in the control group, these differences achieving statistical significance at the 5% level.

D. LOWER FACIAL HEIGHT

Lower anterior facial height (sp-gn) was not found to be significantly different in the study sample when comparisons were made with the control category. However, the mean values of this linear dimension were 72.45mm for the study sample and 75.60mm for the control group, the value of this measurement being 3.15mm less in the study sample, and statistical analysis revealed this difference to approach significance at the 5% level (p=0.068).

E. MAXILLARY RELATIONSHIPS TO THE CRANIAL BASE.

Several significant differences were found in the relationship of the maxilla to the cranial base when the control group and study sample were compared. As described previously, the greater mean values of upper anterior and posterior facial height (n-sp, s-pm) in the sample category were found to be significant at the 5% level, indicating that the maxillary plane (sp-pm) was positioned more inferiorly relative to the cranial base in the study sample when compared to controls. However, no significant difference was observed in the angulation of the maxillary plane to the nasion-sella line (NSL/NL) between the two categories (p=0.870). Similarly no significant differences were found between the control and sample categories in the mean values describing the location of the posterior border of the maxilla (pm-s-ba) (p=0.605). However, as the maxillary plane is positioned more inferiorly relative to the nasion-sella line in the study sample, the lack of significant difference in the angle pm-s-ba between the two categories demonstrates a more anterior location of the posterior border of the maxilla in the study sample.

The overall length of the maxilla (sp-pm) was observed to be significantly greater in the study sample (p=0.017) when comparisons were made with controls, the difference between the mean values of this dimension being 2.65mm.

Maxillary prognathism (s-n-sp) was not found to be significantly different between the control and sample categories (p=0.153).

Maxillary prognathism (s-n-ss) was also not found to be significantly different between the control or sample categories when comparisons were made ($p=0.721$).

Though the overall length of the maxilla (sp-pm) was significantly greater at the 5% level in the study sample, the length of the maxilla at the alveolar level (ss-pm) was not observed to be larger in the study sample when comparisons were made with the control category ($p=0.184$).

F. DENTAL RELATIONSHIPS.

Many linear and angular variables describing maxillary and mandibular dental relationships were found to be significantly different when the control and sample categories were compared.

The linear distance of the upper central incisor tip to the anterior limit of the maxillary plane (sp-is) was found to be significantly smaller in the study sample when compared with controls ($p=0.000$). The difference between the mean values for this dimension was 4.59mm and observed to be highly significant at the 0.1% level.

No significant difference in the angulation of the upper central incisor to the maxillary plane (IL_s/NL) was found when the sample and control categories were compared ($p=0.176$).

The labio-palatal dimension of the incisal edge of the upper central incisor (is_1-is_2) was found to be significantly greater in the study sample (p=0.000) on comparison with controls, the mean dimensions of this measurement being 5.36mm for the study sample and 1.19mm for the control group. Similarly, the labio-lingual dimension of the incisal edge of the lower central incisor (ii_1-ii_2) was also significantly larger in the study sample when compared with controls, the mean dimensions of this variable being 2.95mm and 0.59mm respectively.

Measurements of overjet (oj) and overbite (ob) were also found to show highly significant differences at the 0.1% level when the control and sample categories were compared. Overjet was seen to be significantly smaller in the study sample (p=0.000), the mean value for this category being 1.66mm whereas the mean value for the control group was 5.38mm, with a difference of 3.72mm between the two groups. Overbite measurements also showed similar differences, the mean value for the study sample being 0.28mm and the mean value for the control group being 3.51mm. This variable was thus significantly less by 3.23mm in the sample category (p=0.000) when comparisons were made.

No significant difference in the inclination of the lower central incisor to the mandibular plane (IL_i/ML) was found. However, the mean value of this dimension was less in the study sample than in the control group by 3.27°, and this difference approached statistical significance at the 5% level (p=0.061). The linear distance between the tip of the lower central incisor to the anterior limit of the mandibular plane (ii-gn) was not seen to be significantly different in the study sample when compared with controls (p=0.106).

G. TOOTH LENGTHS.

The values recorded for both upper and lower central incisor lengths were both found to be significantly less in the study sample when compared to controls. For the upper incisors (is-as) the mean value was found to be 23.68mm in the sample category, compared with a mean value of 28.65mm for the control category, the difference of 4.97mm achieving statistical significance at the 0.1% level (p=0.000).

Similar results were obtained for the lower central incisors (ii-ai), a mean value of 22.25mm being recorded for the study sample and 25.56mm for the control group. The difference between the mean values was 3.31mm, this measurement also being statistically significant at the 0.1% level (p=0.000).

H. MANDIBULAR RELATIONSHIPS

Significant differences were found in the relationship of the mandible to both the cranial base and the maxilla when the control and sample categories were compared. Significant differences were also recorded in mandibular morphology when such comparisons were carried out.

The position of the mandibular condyle relative to the cranial base (n-s-ar,s-ar) was not found to be significantly different between the control and sample categories (p=0.890 and p=0.996

respectively).

The overall length of the mandible (pgn-cd) was significantly greater in the study sample ($p=0.000$), the difference between the mean lengths of this variable being 6.86mm when compared with the controls.

Ramus length (ar-tgo) was also found to be significantly greater in the study sample when compared to controls ($p=0.000$), the difference between the mean values of this dimension being 5.40mm.

The length of the body of the mandible (pg-tgo) was similarly significantly larger in the study sample when compared with controls ($p=0.000$) the difference between the mean values of this variable being 5.89mm.

The angulation between the mandibular plane and ramus line (ML/RL) was observed to be significantly smaller in the sample group ($p=0.011$), the difference between the mean values and this angular dimension for the control and sample categories being recorded as 3.83°. The angulation of the mandibular plane relative to the nasion-sella line (NSL/ML) was also smaller in the sample group when compared to the control group ($p=0.001$). The angulation of the mandibular plane relative to the maxillary plane (NL/ML) was similarly smaller in the study sample when comparisons were made with the control category ($p=0.000$), the difference between the mean values of these measurements being 5.07° for the angle NSL/ML and 5.25° for the angle NL/ML.

The mandibular base line was also found to be more inclined towards the nasion-sella line (NSL/MBL), the mean value of this dimension being significantly less in the sample group (p=0.010). The difference between the mean value of this angle when compared with that recorded for controls was 3.16°.

The mandible was found to be more prognathic in the sample category, when compared with controls, the mean value of this angular dimension s-n-pg being 2.97° greater in the study sample, and the mean value of the angular dimension s-n-sm being 2.33° greater in the sample category (p=0.011) when comparisons were made.

Relative prognathism (ss-n-sm) was demonstrated to be significantly less in the sample group when values recorded for this angle were compared with controls (p=0.003). The mean values of this measurement were 3.34° for the control group and 2.13° for the study sample indicating a tendency towards a skeletal class III dental base relationship.

Although the mandible was found to be more prognathic in the study sample, relative madibular prognathism (ss-n-pg) was not found to be significantly different when the control and sample categories were compared (p=0.295).

I. SOFT TISSUES

Many soft tissue differences were seen between the control and sample categories which reflected previously recorded hard tissue saggital relationships.

No overall difference in profile form (NFL/NCL) was found when comparisons were made between the control and sample categories ($p=0.714$).

The vertical height of the base of the nose (n_s-sn_s) was not found to be significantly different in the study sample when compared to the control group ($p=0.486$). Nasal protusion (lnt to n-ss) was however, found to be significantly greater in the study sample when compared to the control catogory ($p=0.000$). The difference between the mean values of this variable was recorded as 2.97mm. The length of the dorsum of the nose (n_s-prn) was also found to be greater in the study sample when comparisons were made with controls ($p=0.025$), the difference between the mean values for both groups being 3.10mm, achieving statistical significance at the 5% level. No difference in the vertical position of the nose (s-n_s-unt) was observed when the control and sample categories were compared ($p=0.237$).

The depth of the nasolabial curvature (sn to lnt-ls) was found to be significantly greater in the study sample when compared with controls ($p=0.000$), the difference between the mean values of this variable being 1.86mm. Upper lip prominence (ls to NCL) was observed to be significantly less in the study sample ($p=0.000$) when compared to controls, the difference in the mean values of this variable being 4.94mm. No significant difference in upper lip protusion (s-n_s-ss_s) was observed when the control and sample categories were compared ($p=0.829$). These differences in nasiolabial curvature, upper lip prominence and upper lip protusion when considered collectively indicate a less concave and more flat profile to the upper lip in the study sample when compared with controls. The height of the upper lip as measured from the lip contact position to the maxillary plane (sto to NL) was not found to be significantly different when the control and sample categories were compared ($p=0.222$). However, as the maxillary plane (NL) was observed to be positioned more inferiorly in the study sample, and the nose was not found to differ in its vertical relationship between control and sample categories, the overall length of the upper lip was effectively seen to be increased in the study sample when compared with controls.

Lower lip prominence (li to NCL) was found to be significantly less in the study sample when comparisons were made with controls ($p=0.000$), the difference between the mean values of this dimension being 4.81mm. Lower lip protusion ($s-n_s-sm_s$) was found to be greater in the study sample when compared to the control category ($p=0.008$), the difference between the mean values of this variable being calculated at 2.61°. No significant difference was found in the depth of the labiomental fold (sm_s to $li-pg_s$) when control and sample categories were compared ($p=0.300$). Lower lip length (sto to ML) was found to be significantly less in the study sample when comparisons were made to the control category ($p=0.020$), the difference between the mean values of this variable in the two categories being 2.60mm.

The location of the lip contact point in relation to the occlusal plane (sto to OL_s) was found to be more inferior in the study sample when compared to controls (p=0.000). This corresponds to the observed greater length of the upper lip and shorter lower lip demonstrated in the study sample when comparisons were made with the control category.

Soft tissue chin protusion ($s-n_s-pg_s$) was demonstrated to be significantly greater in the study sample when compared to controls (p=0.001), reflecting the similar difference observed in the corresponding hard tissue reference points (s-n-pg). The difference between the control and sample mean values of soft tissue chin protusion was found to be 3.53mm compared with 2.97mm for the difference between the control and sample mean values of the corresponding skeletal variable.

J. ASSOCIATIONS BETWEEN FACIAL HEIGHT AND GENERAL ASPECTS OF HARD AND SOFT TISSUE MORPHOLOGY.

Associations between facial height and craniofacial variables describing general aspects of facial morphology were expressed by correlation coefficients for both the control and sample categories. Many associations were identified between these variables within the control group, but fewer associations were found between the variables in the study sample.

(i) Facial height and mandibular relations

For the control group, no associations were identified between total and upper facial height and mandibular relations. A small negative association was however identified between lower anterior facial height and mandibular prognathism (r=-0.332, p=0.018). Small positive correlations were found between lower anterior facial height and both relative alveolar prognathism (r=0.397, p=0.006) and relative mandibular prognathism (r=0.335, p=0.017). A substantial positive association was similarly identified between lower anterior facial height and mandibular base line angulation (r=0.593, p=0.000).

In the study sample, a small negative correlation was identified between lower anterior facial height and relative prognathism (r=-0.362, p=0.016) and a small positive association was found between this component of facial height and mandibular base line angulation (r=0.358, p=0.017).

(ii) Facial height and incisal relations

For the control group, small positive associations were identified between total facial height and both overbite (r=0.272, p=0.045) and lower incisal edge width (r=0.283, p=0.039). Similar small positive associations were also found between lower anterior facial height and both overbite (r=0.264, p=0.050) and lower incisal edge width (r=0.363, p=0.011).

In the study sample no correlations were found between facial height and variables describing incisal relations.

(iii) Facial height and soft tissue relations

In the control group, small negative correlations were observed between total facial height and both upper and lower lip prominence (r=-0.285, p=0.038 and r=-0.443, p= 0.002 respectively). A small negative association was also identified between total facial height and soft tissue chin protusion (r=-0.304, p=0.028). A moderate positive association was also seen between total facial height and upper lip height, achieving statistical significance at the 0.1% level (r=0.688, p=0.000). Similar associations were also seen between lower anterior facial height and these variables, with moderate negative correlations identified between lower facial height and upper and lower lip prominence (r=-0.405, p=0.005 and r=-0.498, p=0.001) and also soft tissue chin protusion (r=-0.313, p=0.025). In addition, a small positive association was also found between lower anterior facial height and saggital lip relations (r=0.295, p=0.032).

In the study sample, fewer significant associations were identified. A small negative correlation was observed between upper facial height and lower lip protusion (r=-0.340, p=0.023), and a marked positive association was found between total facial height and upper lip height (r=0.705, p=0.000). A small negative correlation was also observed between lower anterior facial height and lower lip prominence (r=-0.284, p=0.049).

SUMMARY OF RESULTS.

Many significant differences were found in the linear and angular variables describing cranial base, dentoalveolar and soft tissue morphology between the control and study samples. The results obtained are summarised in table 20,21 and may be visualised by means of mean plots in figures 25 and 26 .

1. No significant differences were found between the control and sample categories in the dimensions of the posterior cranial base and the cranial base flexural angle. However, the length of the anterior cranial base was found to be significantly greater in the study sample.

2. No significant difference in total anterior facial height was found between the control and sample categories, though total posterior facial height was significantly greater in the study sample. Upper anterior and posterior facial height were found to be significantly greater in the sample group when compared to controls, and no significant difference in lower anterior facial height was found between the two categories.

3. The maxilla was found to be placed more antero-inferiorly in the study sample when comparisons were made with controls. The overall length of the maxilla was also greater in the study sample, and was not found to be significantly different between the two groups.

4. The length of the upper central incisor and the distance of its tip to the maxillary plane were both found to be significantly less in the study sample when compared to controls. No difference in the angulation of the upper incisor to the maxillary plane was found

between the two categories. The labiopalatal width of the incisal edge of the upper central incisor was observed to be significantly greater in the study sample when comparisons were made with the control category, and a similar result was obtained for the width of the incisal edge of the lower central incisor.

Measurements of overjet and overbite were both found to be significantly less in the study sample when control and sample categories were compared.

No difference in the position of the incisal edge of the lower central incisor relative to the mandibular plane was found between control and sample categories, though the length of the lower central incisor was found to be significantly less in the study sample.

5. The position of the mandibular condyle relative to the cranial base was not found to be significantly different between control and sample categories. Overall mandibular length, ramus length and body length were all found to be significantly greater in the study sample when compared to controls. The gonial angle was found to be more acute in the study sample and the mandibular plane found to be more inclined towards both the anterior cranial base and the maxillary plane when comparisons were carried out. Similarly, the mandibular base line was also more inclined towards the anterior cranial base in the study sample when compared to controls.

Mandibular prognathism was observed to be significantly greater in the sample category in comparison to the controls, whereas relative mandibular prognathism was not found to be significantly different between the two categories.

6. Highly significant soft tissue differences were also seen between the control group and study sample. No overall difference in facial profile form was found between the two categories. The vertical height of the base of the nose was not found to be significantly different between the two groups, but nasal protusion and the length of the dorsum of the nose were both significantly greater in the study sample when compared to controls. No significant difference in the vertical position of the nose was observed between the two categories.

The depth of the nasolabial curvature was significantly greater in the sample category. However, upper lip prominence was significantly less in this group and upper lip protusion was not significantly different between the two groups. The upper lip was found to be longer in the study sample when such comparisons were made.

Lower lip prominence was found to be significantly less in the study sample when compared to controls, though lower lip protusion was found to be greater in this group when comparisons were made. No significant differences were observed in the depth of the labiomental fold between the two categories. Lower lip length was also found to be significantly less in the study sample in comparison with controls.

The lip contact position was found to be positioned more inferiorly relative to the occlusal plane in the study sample in comparison to the control category. Soft tissue chin protusion was demonstrated to be significantly greater in the sample category compared to controls. A tabulated summary of these findings is shown in table 20.

7. Analysis of the results demonstrated some associations between facial height and craniofacial morphology in the control group, but few such associations in the sample category. Few substantial associations were found in either category.

(i) Facial height and mandibular relations

In the control group a substantial positive association was found between lower facial height and mandibular base line angulation. In the study sample, a small positive associaton was identified between lower anterior facial height and mandibular base line angulation.

(ii) Facial height and incisal relations

For the control group, small positive correlations were identified between total facial height and both overbite and lower incisal edge width. Small positive associations were also found between lower anterior facial height and these variables. In the study sample, no correlations were found between facial height and incisal relations.

(iii) Facial height and soft tissue relations

In the control group, a moderate positive association was found between total facial height and upper lip height in the control group. Similar results were obtained for correlations between lower anterior facial height.

In the study sample, fewer associations were seen, with a small negative correlation being identified between upper facial height and lower lip protusion. A marked positive association was also found between total facial height and upper lip height.

Table 15

Cephalometric statistical data for the control group

Variable (N = 40)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
n-s	1	69.0	91.0	78.037	0.711	4.500	20.248	0.261	0.671
n-sp	2	47.0	66.6	57.725	0.625	3.955	15.642	-0.212	0.400
n-gn	3	112.6	144.3	131.712	1.280	8.095	65.525	-0.555	-0.399
s-ba	4	43.9	61.1	50.852	0.734	4.642	21.551	0.556	-0.646
s-ar	5	31.0	52.2	38.477	0.722	4.566	20.844	0.983	0.918
s-pm	6	44.3	62.8	52.617	0.623	3.938	15.507	0.422	0.674
s-tgo	7	75.1	106.0	88.802	1.149	7.267	52.811	0.126	0.041
sp-gn	8	61.4	90.5	75.602	1.119	7.075	50.053	0.162	-0.628
ar-tgo	9	45.8	65.8	54.657	0.771	4.875	23.769	0.007	-0.303
sp-pm	10	50.5	68.0	58.932	0.769	4.866	23.680	0.185	-0.667
ss-pm	11	46.3	60.8	53.302	0.573	3.622	13.120	0.172	-0.212
pgn-cd	12	113.1	144.2	126.330	1.113	7.039	49.551	0.385	0.374
pg-tgo	13	70.5	95.7	84.100	1.036	6.553	42.947	-0.039	-0.656
sp-is	14	41.8	23.3	33.245	0.627	3.967	15.733	-0.156	0.042
ii-gn	15	38.0	53.0	46.165	0.568	3.595	12.921	-0.297	-0.003
n-s-ba	16	121.2	144.7	132.440	0.848	5.360	28.732	0.034	-0.422
n-s-ar	17	113.3	131.0	123.310	0.804	5.087	25.879	-0.306	-0.914
pm-s-ba	18	48.0	69.7	60.917	0.791	5.006	25.057	-0.388	-0.019

Table 15 (Continued)

Cephalometric statistical data for the control group

Variable (N = 40)	NR	Range Min.	Max.	$\bar{x}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
s-n-sp	19	78.9	96.0	87.067	0.631	3.989	15.913	0.288	-0.321
s-n-ss	20	75.1	88.2	81.235	0.525	3.321	11.028	-0.033	-0.589
s-n-sm	21	71.7	85.7	78.577	0.556	3.518	12.375	0.387	-0.730
s-n-pg	22	73.5	88.0	80.235	0.573	3.621	13.114	0.573	-0.234
ss-n-sm	23	0.0	8.0	3.340	0.320	2.022	4.088	0.045	-1.011
ss-n-pg	24	0.1	7.9	2.875	0.303	1.917	3.673	0.467	0.014
NSL/NL	25	-0.1	18.4	7.535	0.636	4.023	16.181	0.274	0.084
NSL/ML	26	22.1	45.0	33.392	0.874	5.525	30.525	0.402	-0.145
NL/ML	27	15.1	35.3	25.857	0.808	5.108	26.090	-0.047	-0.071
NSL/MBL	28	42.6	66.1	54.957	0.785	4.967	24.676	-0.117	0.574
ML/RL	29	112.8	139.4	125.457	0.975	6.196	38.062	-0.175	0.243
IL_s/NL	30	94.2	125.5	107.905	1.225	7.747	60.022	0.312	-0.375
ILi/ML	31	73.1	107.5	87.200	1.266	8.006	64.089	0.207	-0.269
oj	32	-0.5	10.1	5.380	0.348	2.202	4.848	-0.218	0.544
ob	33	-10.1	0.5	-3.507	0.368	2.325	5.405	-0.574	1.094
is_1-is_2	34	0.0	3.2	1.185	0.166	1.052	1.107	-0.080	-1.449
ii_1-ii_2	35	0.0	3.5	0.585	0.146	0.924	0.855	1.461	1.253
is-as	36	23.30	33.70	28.650	0.371	2.345	5.501	-0.092	-0.245
ii-ai	37	20.50	29.30	25.557	0.314	1.987	3.948	-0.530	-0.086
n_s-sn_s	38	48.4	73.5	62.660	0.953	6.027	36.328	-0.088	-0.526

Table 15 (Continued)

Cephalometric statistical data for the control group

Variable (N = 40)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
n_s-prn	39	42.5	65.3	54.445	0.934	5.905	34.872	0.105	-0.850
lnt to n-ss	40	28.1	45.5	35.602	0.606	3.831	14.677	0.522	0.215
s-n_s-unt	41	102.7	132.1	118.895	0.971	6.140	37.699	-0.336	0.423
sto to NL	42	23.4	40.2	29.735	0.638	4.034	16.273	0.556	-0.100
s-n_s-ss_s	43	82.9	99.1	91.880	0.612	3.872	14.995	-0.150	-0.356
sn to lnt-ls	44	5.5	13.5	8.545	0.276	1.745	3.046	0.368	0.425
ls to NCL	45	1.3	12.8	6.772	0.406	2.567	6.590	0.211	-0.346
sto to ML	46	39.7	59.3	48.822	0.750	4.745	22.513	0.071	-0.200
s-n_s-sm_s	47	76.6	91.8	84.522	0.607	3.839	14.737	-0.062	-0.741
sm_s to li-pg_s	48	0.1	9.1	5.872	0.277	1.755	3.080	-0.742	1.754
li to NCL	49	0.4	10.4	4.242	0.401	2.539	6.447	0.573	-0.230
ss_s-n_s-sm_s	50	2.3	11.7	7.320	0.340	2.152	4.632	-0.179	-0.220
sto to OLS	51	116.1	179.0	149.495	2.358	14.911	222.344	-0.026	-0,018
s-n_s-pg_s	52	77.4	95.6	86.180	0.670	4.238	17.964	0.025	-0.478
NFL/NCL	53	-156.3	-132.1	-142.850	0.783	4.955	24.548	-0.156	0.800

linear measurements - millimetres
angular measurements - degrees

Table 16

Cephalometric statistical data for the study sample

Variable (N = 35)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
n-s	1	73.1	88.0	81.083	0.773	4.575	20.930	-0.284	-0.947
n-sp	2	49.5	68.7	60.089	0.731	4.324	18.700	-0.213	0.243
n-gn	3	112.6	151.5	131.083	1.591	9.414	88.620	0.027	0.179
s-ba	4	43.7	60.4	51.966	0.798	4.721	22.289	0.219	-0.773
s-ar	5	27.5	46.6	38.483	0.796	4.709	22.178	-0.310	-0.358
s-pm	6	47.7	64.0	54.994	0.747	4.419	19.529	0.432	-0.708
s-tgo	7	77.7	114.8	93.711	1.447	8.560	73.268	0.262	-0.129
sp-gn	8	59.9	89.7	72.449	1.294	7.655	58.598	0.327	-0.197
ar-tgo	9	48.0	79.4	60.054	1.219	7.211	52.003	0.493	0.206
sp-pm	10	52.5	70.5	61.586	0.756	4.474	20.018	-0.062	-0.628
ss-pm	11	46.8	62.8	54.391	0.569	3.367	11.334	-0.135	0.352
pgn-cd	12	114.4	148.1	133.191	1.446	8.557	73.221	-0.479	-0.041
pg-tgo	13	75.1	103.8	89.986	1.160	6.860	47.061	-0.319	0.242
sp-is	14	20.8	35.3	28.657	0.603	3.567	12.725	0.048	-0.308
ii-gn	15	37.4	58.4	44.514	0.860	5.086	25.869	0.789	0.299
n-s-ba	16	121.1	146.7	131.871	1.141	6.747	45.526	0.172	-0.732
n-s-ar	17	107.0	141.1	123.117	1.173	6.941	48.171	0.149	0.376
pm-s-ba	18	46.9	73.5	61.620	1.127	6.670	44.482	-0.233	-0.425

Table 16 (Continued)

Cephalometric statistical data for the study sample

Variable (N = 35)	NR	Range Min.	Range Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
s-n-sp	19	76.3	97.8	88.583	0.861	5.092	25.927	-0.409	0.231
s-n-ss	20	73.7	88.6	81.534	0.660	3.904	15.238	-0.246	-0.547
s-n-sm	21	72.2	90.1	80.903	0.708	4.190	17.554	-0.326	0.010
s-n-pg	22	73.2	93.2	83.206	0.737	4.362	19.025	-0.179	0.265
ss-n-sm	23	0.2	4.7	2.131	0.205	1.213	1.470	0.277	-0.357
ss-n-pg	24	0.0	9.6	2.354	0.399	2.359	5.563	1.362	1.578
NSL/NL	25	-7.4	16.4	7.706	0.844	4.995	24.948	-0.435	1.158
NSL/ML	26	13.8	46.3	28.320	1.130	6.684	44.675	0.176	0.860
NL/ML	27	9.4	37.3	20.609	1.131	6.694	44.810	0.188	-0.249
NSL/MBL	28	39.2	65.0	51.797	0.913	5.403	29.191	-0.173	0.857
ML/RL	29	112.6	136.3	121.629	1.098	6.497	42.205	0.790	-0.287
IL_s/NL	30	90.3	121.6	105.329	1.451	8.582	73.652	0.124	-0.806
ILi/ML	31	71.0	96.4	83.931	1.131	6.690	44.762	-0.007	-0.882
oj	32	-3.5	11.7	1.657	0.528	3.126	9.770	0.927	1.853
ob	33	-5.1	4.5	-0.277	0.341	2.015	4.061	-0.271	0.849
is_1-is_2	34	3.2	8.5	5.360	0.263	1.557	2.423	0.319	-1.035
ii_1-ii_2	35	1.7	5.8	2.951	0.164	0.968	0.938	1.442	2.047
is-as	36	18.8	28.4	23.677	0.409	2.423	5.869	0.193	-0.437
ii-ai	37	17.0	27.0	22.246	0.401	2.373	5.631	-0.012	0.041
n_s-sn_s	38	54.6	75.6	63.591	0.914	5.407	29.238	0.693	0.049

Table 16 (Continued)

Cephalometric statistical data for the study sample

Variable (N = 35)	NR	Range Min.	Max.	$\bar{X}$ Mean	Standard error of mean $s(\bar{x})$	Standard Deviation s	Variance s^2	Skewness $\sqrt{b1}$	Kurtosis b^2
n_s-prn	39	44.3	68.4	57.549	0.988	5.846	34.174	0.061	-0.069
lnt to n-ss	40	32.2	44.9	38.569	0.466	2.758	7.608	-0.239	0.310
s-n_s-unt	41	104.4	138.1	120.631	1.092	6.462	41.760	0.163	1.146
sto to NL	42	19.8	42.2	28.457	0.835	4.939	24.394	0.690	0.796
s-n_s-ss_s	43	80.8	101.5	91.666	0.790	4.676	21.861	0.019	-0.339
sn to lnt-ls	44	5.8	17.3	10.409	0.444	2.624	6.886	0.605	0.425
ls to NCL	45	2.8	22.0	11.711	0.696	4.118	16.957	-0.145	0.462
sto to ML	46	37.7	58.4	46.226	0.787	4.658	21.694	0.444	0.121
s-n_s-sm_s	47	78.9	95.6	87.160	0.753	4.452	19.821	0.287	-0.712
sm_s to li-pg_s	48	2.9	9.4	5.457	0.284	1.680	2.821	0.334	-0.345
li to NCL	49	0.4	14.6	9.054	0.592	3.505	12.287	-0.492	-0.261
ss_s-n_s-sm_s	50	0.5	9.8	4.660	0.446	2.638	6.597	0.324	-0.780
sto to OLS	51	141.3	178.8	166.209	1.714	10.143	102.874	-1.007	0.293
s-n_s-pg_s	52	79.3	100.0	89.709	0.802	4.742	22.484	0.263	-0.177
NFL/NCL	53	-153.5	-131.4	-143.309	0.985	5.827	33.949	0.264	-0.491

linear measurements - millimetres
angular measurements - degrees

Table 17

Comparison of control group and study sample

Variable		Number of cases	$\bar{X}$ Mean	Standard Deviation	Standard Error	Value of F	2 tail Prob.	Value of t	Degrees of Freedom	2 Tail Prob.
n-s	sample	35	81.031	4.575	0.733					
	control	40	78.038	4.500	0.711	1.03	0.915	2.90	73	0.005**
n-sp	sample	35	60.089	4.324	0.731					
	control	40	57.725	3.955	0.625	1.20	0.587	2.47	73	0.016*
n-gn	sample	35	131.083	9.414	1.591					
	control	40	131.713	8.095	1.280	1.35	0.361	-0.31	73	0.756
s-ba	sample	35	51.966	4.721	0.798					
	control	40	50.853	4.642	0.734	1.03	0.914	1.03	73	0.307
s-ar	sample	35	38.483	4.709	0.796					
	control	40	38.478	4.566	0.722	1.06	0.847	0.00	73	0.996
s-pm	sample	35	54.994	4.419	0.747					
	control	40	52.618	3.938	0.623	1.26	0.485	2.46	73	0.016*
s-tgo	sample	35	93.711	8.560	1.447					
	control	40	88.803	7.267	1.149	1.39	0.323	2.69	73	0.009**
sp-gn	sample	35	72.449	7.655	1.294					
	control	40	75.603	7.075	1.119	1.17	0.631	-1.85	73	0.068
ar-tgo	sample	35	60.054	7.211	1.219					
	control	40	54.658	4.875	0.771	2.19	0.019	3.84	73	0.000***
sp-pm	sample	35	61.586	4.474	0.756					
	control	40	58.933	4.866	0.769	1.18	0.621	2.45	73	0.017*
ss-pm	sample	35	54.391	3.367	0.569					
	control	40	53.303	3.622	0.573	1.16	0.668	1.34	73	0.184

Table 17 (continued)

Comparison of control group and study sample

Variable		Number of cases	$\bar{X}$ Mean	Standard Deviation	Standard Error	Value of F	2 tail Prob.	Value of t	Degrees of Freedom	2 Tail Prob.
pgn-cd	sample	35	133.191	8.557	1.446					
	control	40	126.330	7.039	1.113	1.48	0.239	3.81	73	0.000***
pg-tgo	sample	35	89.986	6.860	1.160					
	control	40	84.100	6.553	1.036	1.10	0.778	3.80	73	0.000***
sp-is	sample	35	28.657	3.567	0.603					
	control	40	33.245	3.967	0.627	1.24	0.532	-5.24	73	0.000***
ii-gn	sample	35	44.514	5.086	0.860					
	control	40	46.165	3.595	0.568	2.00	0.037	-1.64	73	0.106
n-s-ba	sample	35	131.871	6.747	1.141					
	control	40	132.440	5.360	0.848	1.58	0.166	-0.41	73	0.686
n-s-ar	sample	35	123.117	6.941	1.173					
	control	40	123.310	5.087	0.804	1.86	0.062	-0.14	73	0.890
pm-s-ba	sample	35	61.620	6.670	1.127					
	control	40	60.918	5.006	0.791	1.78	0.085	0.52	73	0.605
s-n-sp	sample	35	88.583	5.092	0.861					
	control	40	87.068	3.989	0.631	1.63	0.142	1.44	73	0.153
s-n-ss	sample	35	81.534	3.904	0.660					
	control	40	81.235	3.321	0.525	1.38	0.329	0.36	73	0.721
s-n-sm	sample	35	80.903	4.190	0.708					
	control	40	78.578	3.518	0.556	1.42	0.291	2.61	73	0.011*

Table 17 (continued)

Comparison of control group and study sample

Variable		Number of cases	$\bar{X}$ Mean	Standard Deviation	Standard Error	Value of F	2 tail Prob.	Value of t	Degrees of Freedom	2 Tail Prob.
s-n-pg	sample	35	83.206	4.362	0.737					
	control	40	80.235	3.621	0.573	1.45	0.262	3.22	73	0.002**
ss-n-sm	sample	35	2.131	1.213	0.205					
	control	40	3.340	2.022	0.320	2.78	0.003	-3.08	73	0.003**
ss-n-pg	sample	35	2.354	2.359	0.399					
	control	40	2.875	1.917	0.303	1.51	0.211	-1.05	73	0.295
NSL/NL	sample	35	7.706	4.995	0.844					
	control	40	7.535	4.023	0.636	1.54	0.192	0.16	73	0.870
NSL/ML	sample	35	28.320	6.684	1.130					
	control	40	33.393	5.525	0.874	1.46	0.251	-3.60	73	0.001***
NL/ML	sample	35	20.609	6.694	1.131					
	control	40	25.858	5.108	0.808	1.72	0.104	-3.84	73	0.000***
NSL/MBL	sample	35	51.797	5.403	0.913					
	control	40	54.958	4.967	0.785	1.18	0.609	-2.64	73	0.010**
ML/RL	sample	35	121.629	6.497	1.098					
	control	40	125.458	6.169	0.975	1.11	0.751	-2.62	73	0.011*
ILs/NL	sample	35	105.329	8.582	1.451					
	control	40	107.905	7.747	1.225	1.23	0.535	-1.37	73	0.176
ILi/ML	sample	35	83.931	6.690	1.131					
	control	40	87.200	8.006	1.266	1.43	0.289	-1.90	73	0.061

Table 17 (continued)

Comparison of control group and study sample

Variable		Number of cases	$\bar{X}$ Mean	Standard Deviation	Standard Error	Value of F	2 tail Prob.	Value of t	Degrees of Freedom	2 Tail Prob.
oj	sample	35	1.657	3.126	0.528					
	control	40	5.380	2.202	0.348	2.02	0.036	-6.02	73	0.000***
ob	sample	35	-0.277	2.015	0.341					
	control	40	-3.508	2.325	0.368	1.33	0.399	6.38	73	0.000***
is_1-is_2	sample	35	5.360	1.557	0.263					
	control	40	1.185	1.052	0.166	2.19	0.019	13.75	73	0.000***
ii_1-ii_2	sample	35	2.951	0.968	0.164					
	control	40	0.585	0.924	0.146	1.10	0.775	10.82	73	0.000***
is-as	sample	35	23.677	2.423	0.409					
	control	40	28.650	2.345	0.371	1.07	0.840	-9.02	73	0.000***
ii-ai	sample	35	22.246	2.373	0.401					
	control	40	25.557	1.987	0.314	1.43	0.284	-6.58	73	0.000***
n_s-sn_s	sample	35	63.591	5.407	0.914					
	control	40	62.660	6.027	0.953	1.24	0.522	0.70	73	0.486
n_s-prn	sample	35	57.549	5.846	0.988					
	control	40	54.445	5.905	0.934	1.02	0.958	2.28	73	0.025*
lnt to n-ss	sample	35	38.569	2.758	0.466					
	control	40	35.603	3.831	0.606	1.93	0.054	3.80	73	0.000***
s-n_s-unt	sample	35	120.631	6.462	1.092					
	control	40	118.895	6.140	0.971	1.11	0.753	1.19	73	0.237

Table 17 (continued)

Comparison of control group and study sample

Variable		Number of cases	$\bar{X}$ Mean	Standard Deviation	Standard Error	Value of F	2 tail Prob.	Value of t	Degrees of Freedom	2 Tail Prob.
sto to NL	sample	35	28.457	4.939	0.835					
	control	40	29.735	4.034	0.638	1.50	0.222	-1.23	73	0.222
$s-n_s-ss_s$	sample	35	91.666	4.676	0.790					
	control	40	91.880	3.872	0.612	1.46	0.255	-0.22	73	0.829
sn to lnt-ls	sample	35	10.409	2.624	0.444					
	control	40	8.545	1.745	0.276	2.26	0.015	3.66	73	0.000***
ls to NCL	sample	35	11.711	4.118	0.696					
	control	40	6.773	2.567	0.406	2.57	0.005	6.31	73	0.000***
sto to ML	sample	35	46.226	4.658	0.787					
	control	40	48.823	4.745	0.750	1.04	0.918	-2.38	73	0.020*
$s-n_s-sm_s$	sample	35	87.160	4.452	0.753					
	control	40	84.553	3.839	0.607	1.34	0.370	2.72	73	0.008**
sm_s to $li-pg_s$	sample	35	5.457	1.680	0.284					
	control	40	5.873	1.755	0.277	1.09	0.799	-1.04	73	0.300
li to NCL	sample	35	9.054	3.505	0.592					
	control	40	4.243	2.539	0.401	1.91	0.053	6.87	73	0.000***
$ss_s-n_s-sm_s$	sample	35	4.660	2.638	0.446					
	control	40	7.320	2.152	0.340	1.50	0.220	-4.81	73	0.000***

Table 17 (continued)

Comparison of control group and study sample

Variable		Number of cases	$\bar{X}$ Mean	Standard Deviation	Standard Error	Value of F	2 tail Prob.	Value of t	Degrees of Freedom	2 Tail Prob.
sto to OLS	sample	35	166.209	10.143	1.714					
	control	40	149.495	14.911	2.358	2.16	0.024	5.59	73	0.000***
$s\text{-}n_s\text{-}pg_s$	sample	35	89.709	4.742	0.802					
	control	40	86.180	4.238	0.670	1.25	0.496	3.40	73	0.001***
NFL/NCL	sample	35	-143.309	5.827	0.985					
	control	40	-142.850	4.955	0.783	1.38	0.327	-0.37	73	0.714

* $p<0.05$
** $p<0.01$
*** $p<0.001$

linear measurements = millimetres
angular measurements = degrees

Table 18

Correlations between facial height and general aspects of craniofacial form for the control group

Variable	n-sp	n-gn	sp-gn	s-n-sm	s-n-pg	ss-n-sm	ss-n-pg	NSL/ML	NSL/MBL	ML/RL
n-sp		0.527	0.450	-0.306	-0.286	-0.075	-0.110	0.221	0.207	0.140
n-gn	0.527		0.862	-0.310	-0.391	0.228	0.204	0.411	0.582	-0.024
sp-gn	0.450	0.862		-0.212	-0.332*	0.397**	0.335*	0.390	0.593***	-0.096

Variable	IL_s/NL	IL_i/ML	oj	ob	is_1-is_2	ii_1-ii_2	s-n_s-ss_s	ls to NCL	s-n_s-sm_s	li to NCL
n-sp	0.260	0.008	-0.192	0.025	-0.103	0.011	-0.213	0.069	-0.167	-0.079
n-gn	0.026	0.264	-0.047	0.272*	0.095	0.283*	-0.140	-0.285*	-0.243	-0.443**
sp-gn	-0.148	0.317	0.103	0.264*	0.188	0.363*	-0.082	-0.405**	-0.251	-0.498***

Variable	ss_s-n_s-sm_s	ss_s-n_s-pg_s	sto to NL	sto to ML	sto to OL_s
n-sp	-0.089	-0.192	-0.078	0.087	0.260
n-gn	0.175	-0.304*	0.688***	0.798	0.017
sp-gn	0.295*	-0.313*	0.844	0.908	-0.210

(Pearson Correlation Coefficients)

* $p<0.05$
** $p<0.01$
*** $p<0.001$

Table 19

Correlations between facial height and general aspects of craniofacial form for the study sample

Variable	n-sp	n-gn	sp-gn	s-n-sm	s-n-pg	ss-n-sm	ss-n-pg	NSL/ML	NSL/MBL	ML/RL
n-sp		0.569	0.138	-0.552	-0.531	0.111	0.035	0.355	0.421	0.189
n-gn	0.569		0.887	-0.223	-0.292	-0.260	-0.169	0.465	0.472	0.343
sp-gn	0.138	0.887		0.030	-0.081	-0.362*	-0.275	0.378	0.358*	0.294

Variable	IL_s/NL	IL_i/ML	oj	ob	is_1-is_2	ii_1-ii_2	$s-n_s-ss_s$	ls to NCL	$s-n_s-sm_s$	li to NCL
n-sp	0.118	0.009	-0.163	-0.115	-0.068	-0.193	-0.357	0.228	-0.340*	0.206
n-gn	0.174	-0.161	-0.111	-0.026	-0.081	-0.137	-0.137	-0.011	-0.048	-0.110
sp-gn	0.133	-0.167	-0.013	0.008	-0.086	-0.081	0.048	-0.166	0.128	-0.284*

Variable	$ss_s-n_s-sm_s$	$ss_s-n_s-pg_s$	sto to NL	sto to ML	sto to OL_s
n-sp	-0.052	-0.278	-0.021	-0.227	0.210
n-gn	-0.160	-0.111	0.705***	0.829	0.240
sp-gn	-0.131	-0.002	0.867	0.883	0.167

(Pearson Correlation Coefficients)

* $p<0.05$
** $p<0.01$
*** $p<0.001$

Table 20

Summary of the differences between the means of the control group and study sample

NR	Variable	Difference between $\bar{X}$ (Sample-Control)	Greater than/ Lesser than (Sample w.r.t. control)	Level of Significance
1	n-s	3.045	>	**
2	n-sp	2.364	>	*
3	n-gn	-0.630	<	n.s.
4	s-ba	1.113	>	n.s.
5	s-ar	0.005	>	n.s.
6	s-pm	2.376	>	*
7	s-tgo	4.908	>	**
8	sp-gn	-3.154	<	n.s. (p=0.068)
9	ar-tgo	5.396	>	***
10	sp-pm	2.653	>	*
11	ss-pm	1.088	>	n.s.
12	pgn-cd	6.861	>	***
13	pg-tgo	5.886	>	***
14	sp-is	-4.588	<	***
15	ii-gn	-1.651	<	n.s.
16	n-s-ba	-0.569	<	n.s.
17	n-s-ar	-0.193	<	n.s.
18	pm-s-ba	0.702	>	n.s.
19	s-n-sp	1.512	>	n.s.
20	s-n-sp	0.299	>	n.s.
21	s-n-sm	2.325	>	*
22	s-n-pg	2.971	>	**
23	ss-n-sm	-1.209	<	**
24	ss-n-pg	-0.521	<	n.s.
25	NSL/NL	0.171	>	n.s.
26	NSL/ML	-5.073	<	***
27	NL/ML	-5.249	<	***
28	NSL/MBL	-3.161	<	**
29	ML/RL	-3.829	<	*
30	$1L_s$/NL	-2.576	<	n.s.
31	$1L_i$/ML	-3.269	<	n.s. (p=0.061)

Table 20 (continued)

Differences between the means of the control group and study sample

NR	Variable	Difference between $\bar{X}$ (Sample-Control)	Greater than/ Lesser than (Sample w.r.t. control)	Level of Significance
32	oj	-3.723	<	***
33	ob	3.231	<	***
34	is_1-is_2	4.175	>	***
35	ii_1-ii_2	2.366	>	***
36	is-as	-4.973	<	***
37	ii-ai	-3.311	<	***
38	n_s-sn_s	0.931	>	n.s.
39	ns-prn	3.104	>	*
40	lnt to n-ss	2.966	>	***
41	s-n_s-unt	1.736	<	n.s.
42	sto to NL	-1.278	<	n.s.
43	s-n_s-ss_s	-0.214	<	n.s.
44	sn to lnt-ls	1.864	>	***
45	ls to NCL	4.938	>	***
46	sto to ML	-2.597	<	*
47	s-n_s-sm_s	2.607	>	**
48	sm_s to li-pgs	-0.416	<	n.s.
49	li to NCL	4.811	>	***
50	ss_s-n_s-sm_s	-2.660	<	***
51	sto to OL_s	16.714	>	***
52	s-n_s-pgs	3.529	>	***
53	NFL/NCL	-0.459	>	n.s.

>= greater value
< = lesser value

* $p<0.05$
** $p<0.01$
*** $p<0.001$

linear measurements in millimetres
angular measurements in degrees

Table 21

Summary of correlations between facial height and craniofacial morphology for the control group

Variable	Variable	Correlation (r)	Significance level
n-gn	ob	0.272	*
n-gn	ii_1-ii_2	0.283	*
n-gn	ls to NCL	-0.285	*
n-gn	li to NCL	-0.443	**
n-gn	s-n_s-pg_s	-0.304	*
n-gn	sto to NL	0.688	***
sp-ng	s-n-pg	-0.332	*
sp-gn	ss-n-sm	0.397	**
sp-gn	ss-n-pg	0.335	*
sp-gn	NSL/MBL	0.593	***
sp-gn	ob	0.264	*
sp-gn	ii_1-ii_2	0.363	*
sp-gn	ls to NCL	-0.405	**
sp-gn	li to NCL	-0.498	***
sp-gn	ss_s-n_s-sm_s	0.295	*
sp-gn	s-n_s-pg_s	-0.313	*

Table 22

Summary of correlations between facial height and craniofacial morphology for the study sample

Variable	Variable	Correlation (r)	Significance level
n-sp	s-n_s-sm_s	-0.340	*
n-gn	sto to NL	0.705	***
sp-gn	ss-n-sm	-0.362	*
sp-gn	NSL/MBL	0.358	*
sp-gn	li to NCL	-0.284	*

* $p<0.05$
** $p<0.01$
*** $p<0.001$

FIGURE 25. Mean plot control group.

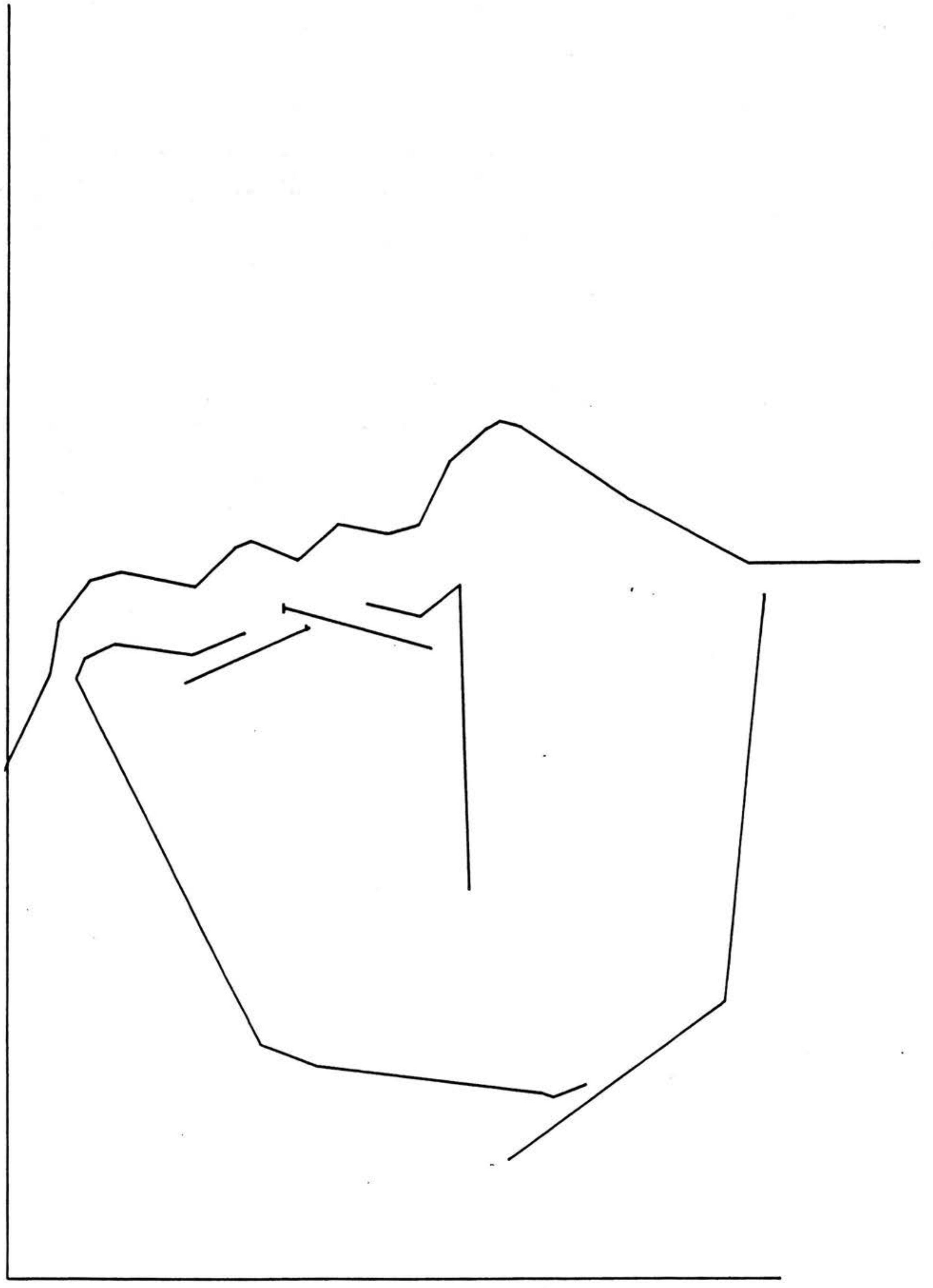
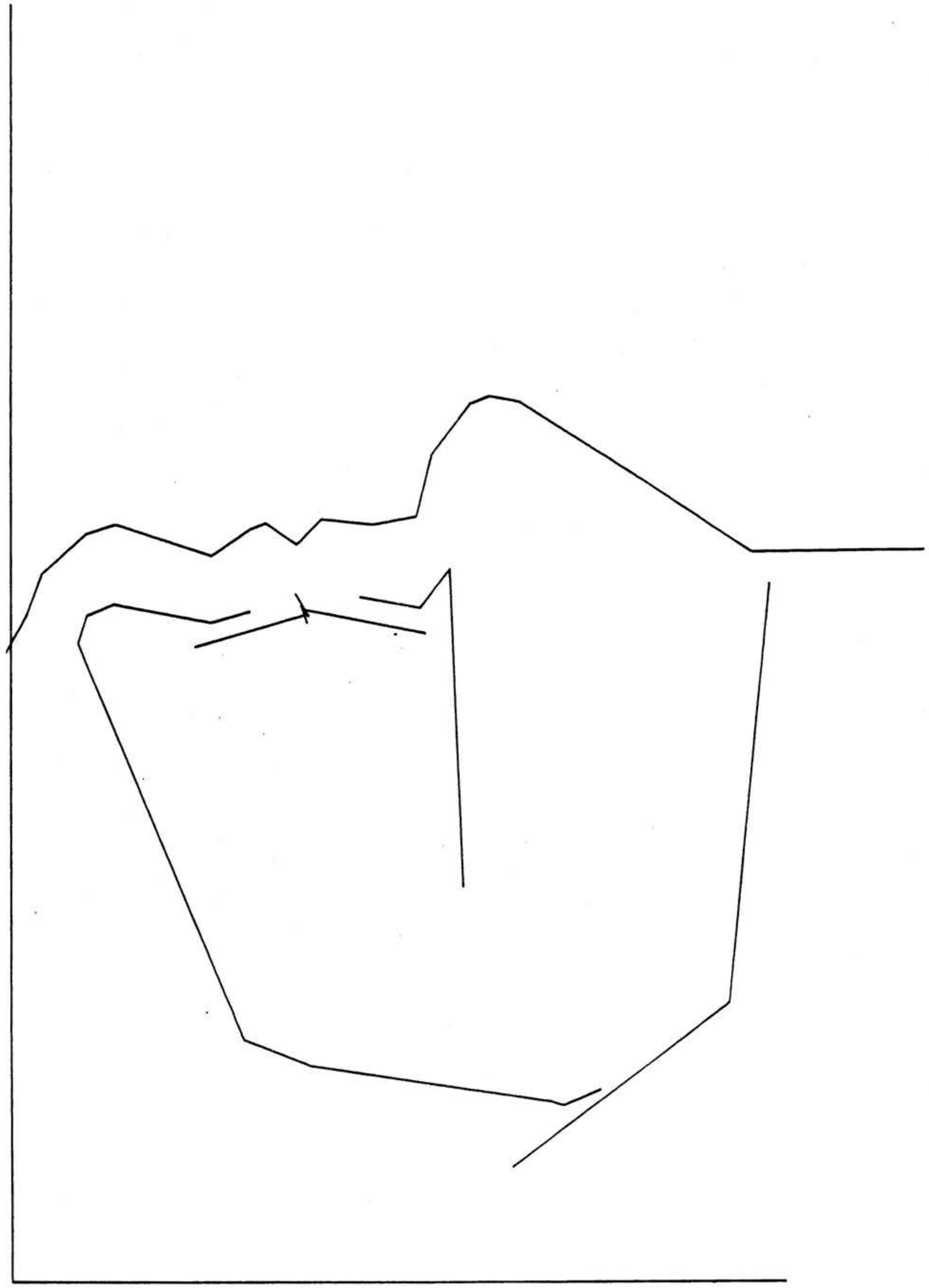


FIGURE 26. Mean plot study sample.



CHAPTER 7

DISCUSSION

A. INTRODUCTION

The present study was concerned with the differences in craniofacial morphology that may be identified in the presence of advanced dental attrition, and the influences of the ageing process on facial form after the third decade of life. A method by which subjects in this age group with this form of advanced tooth wear could be compared with a control group of adult subjects was established by modifying an existing computer programme designed for orthodontic measurement purposes. The results of the analysis of both sample and control data were written to computer disk file with the aid of this programme, enabling statistical comparisons to be carried out using the facilities of the Edinburgh Regional Computing Centre (ERCC).

The errors in all the measurement systems were tested, consisting of both equipment and method error. The error due to reproducibility at an x-co-ordinate was 0.16mm (table 8) and for the y-co-ordinate 0.20mm (table 9). The error due to linearity over the active field of the digitiser was not greater than 0.5mm (table 10). The total error for point placement on the radiograph included both point placement error on the part of the operator and the point location error by the digitiser. This total error ranged from 0.038mm to 0.907mm for the linear measurements and 0.019° to 3.118° for the angular dimensions, the angular variable sto to OL_s showing the greatest total error (3.118°) due to the difficulties involved in locating the soft tisue reference point stomion.

The analysis of the cephalometric radiograph consisted of the location of 51 points defining cephalometric landmarks, these points delineating 53 linear and angular variables describing craniofacial and soft tissue morphology. These points were numbered sequentially on an acetate tracing and transferred to the digitiser from the radiograph. This ensured that the correct sequence of digitising was followed. No data was filed until 51 points had been recorded from a tracing, and once filed, a pen plot of the recorded data was obtained for comparison with the original acetate. This acted as a gross error check to ensure the correct sequence was followed. Further error testing was achieved by examination of the statistical analysis of the data. Any location or sequence anomalies were revealed as distribution errors and described by the skewness and kurtosis values obtained, and corrected accordingly.

Cephalometric data was recorded for a total of 75 subjects. A study sample of 35 subjects was obtained as sequential referrals to the Conservation Department of the Edinburgh Dental Hospital. Forty radiographs of adult subjects were obtained from the records held by the Orthodontic Department of the Edinburgh Dental Hospital, and used as a control group. The radiographs used for the control group were randomly selected from those patients in their third decade of life at the time the radiograph was taken. This age group was selected as major growth changes may be considered complete at this age (Bjork 1966).

The radiographic data obtained for both control and sample categories may be considered to be representative of the craniofacial morphology of both young adults and attrition subjects in the Edinburgh area.

Tracings of all radiographs were obtained and digitised, and statistical analysis of the filed data carried out. The statistical analysis of these data revealed the significant differences between control and sample groups when comparisons were made.

Attrition is an integral part of the ageing processes occurring in the dentition (Begg 1977), and its severity depending on clinical circumstance may determine whether or not the wear should be regarded as pathological. The degree of attrition acceptable in a modern population is uncertain (Wise 1977) and must be viewed in the circumstances in which it has occurred (Russell 1987). In the present study, by selecting a control group of young adults without attrition for comparison with a study sample of older subjects with advanced attrition, the effects on craniofacial morphology of both ageing and attritional tooth wear may be recorded. Reference to the data obtained, and to previous studies on ageing throughout adult life enables identification of those effects due to attrition and those due to the ageing process.

B. DISCUSSION OF FINDINGS

(i) Cranial Base

No differences for cranial base angle or dimensions of posterior cranial base were identified when control and sample categories were compared. The absence of differences between the two groups for the dimensions of these variables is not unexpected, as the mean ages of both groups exceeds the end of the second decade of life, after which growth of the cranial base may be considered to be complete (Bjork 1966). The cranial base, being located remotely from the dentoalveolar component of the facial skeleton is also unlikely to be affected by changes in lower facial morphology influenced by attrition (Krogstad & Dahl 1985).

The results did however reveal a more anterior location of the point nasion in the study sample when compared to controls as shown by the greater mean linear dimension of the anterior cranial base in the study sample when comparisons were made. This result is likely to be due to age related changes in the fronto-nasal region rather than a morphological or functional alteration influenced by attrition. Previous studies investigating the changes associated with ageing in the third decade of life (Forsberg 1979, Sarnas & Solow 1980), have demonstrated an antero-inferior displacement of the point nasion throughout the third decade. Comparison of these longitudinal studies suggests that nasion moves antero-inferiorly in the first half of the third decade of life, and anteriorly in the second half of the third decade. The results obtained in the present study support this observed anterior location of nasion after the age of

26 years.

Israel (1968, 1973) reported a 4% increase in most craniofacial dimensions throughout adulthood, though Baer (1956) and Tallgren (1974) did not observe this more anterior location of nasion with advancing age.

This anterior position of nasion in the study sample when compared to controls seems to thus represent an age change, brought about by appositional growth in the fronto-nasal region. The periosteum retains the ability to produce bone throughout life and apposition of bone in adult subjects has been demonstrated to occur (Epker & Frost 1966).

Whereas structures in the anterior cranial base and the sella turcica are normally used for superimposition of cephalometric tracings in orthodontic practice, the absence of significant differences between control and sample categories with regard to posterior cranial base dimensions and flexural angle enables these variables to be used as reference structures for the superimposition of mean plots (fig 25,26) constructed from control and sample data. This superimposition was carried out as a visual aid to interpretation of the data.

The more anterior positioning of the point nasion in the study sample when compared to controls does however mean that linear and angular variables describing craniofacial form involving this point must be interpreted with care, as values of these variables may be

affected by this difference. Consideration was given to this factor in the interpretation of the results of the analysis of the data.

(ii) Facial Height

In the present study, despite the loss of crown height in the incisor region as observed clinically and radiographically in the study sample, **no significant difference in total anterior face height (n-gn) was observed when the control and sample categories were compared.** Previous studies using anthropological specimens exhibiting advanced dental attrition have demonstrated a loss of the lower anterior component of this dimension (sp-gn), (Murphy 1959b & Fishman 1976, Varrela 1990) though whether this result is valid in a modern population is questionable. In the present study, this component (sp-gn) was observed to be less in the study sample when compared to controls, though this did not achieve statistical significance (p=0.068). Forsberg (1979) and Sarnas & Solow (1980) have however demonstrated an increase in total facial height with age in the first half of the third decade of life, and a smaller subsequent increase in this dimension in the second half of this decade. Other workers (Tallgren 1957, Lasker 1953, Baer 1956) have also reported an increase in total facial height with age into adult life. As this dimension was not found to be greater in the study sample when compared with the controls, the **evidence suggests that the presence of advanced attrition appear to have an effect on age changes in total facial height.** It has been suggested (Murphy 1959b, Begg 1977) that continuing vertical growth of the face acts as a mechanism by which loss of occlusal vertical dimension through tooth wear is compensated for. Certainly the results of the present study do not dispute this suggestion, and it may be that adult vertical facial growth does compensate for tooth wear. Tallgren (1957) and Murphy (1968) reported a reduction in total facial height in subjects with dental attrition, the implication here being that any growth mechanisms that may compensate for attrition were not sufficient to prevent loss of vertical facial dimension in the subjects studied. The present study did identify a smaller value for lower anterior facial height in the study sample when compared to controls, though as noted, this did not achieve statistical significance at the 5% level. The findings of Krogstad and Dahl (1985) may be compared to those of the present study, where smaller mean values of faical height in the subjects studied were attributed to the presence of attrition. However, in the present study the results suggest that significant compensation has occurred to prevent loss of total facial height through tooth wear.

Whether or not continuing vertical growth of the face is in fact a compensatory mechanism for attrition, which in its absence continues regardless, is difficult to ascertain. However, compensation implies response to a stimulus and thus it is difficult to regard this vertical growth as a compensatory mechanism, but rather a normal ageing process which occurs irrespective of the attritional process, and may be regarded as compensatory when this tooth wear is present.

In the anthropological specimens such as studied by Murphy 1959b, Fishman 1976 and Varrela 1990, severe attrition was universal in the population, and under these circumstances, continual facial growth throughout life may indeed be regarded as compensatory. However, in studying present day populations, to regard this growth as compensatory is less meaningful other than for descriptive purposes.

In the present study, total posterior facial height was also found to be greater in the study sample when compared to controls, this result being more related to changes in the location of the lower reference point of this variable, which is situated on the mandiblular angle (Vide infra). High F values were however recorded for this variable.

The dimension of total facial height may be subdivided into upper and lower anterior facial heights, and the comparison of these variables between control and sample categories in the present study revealed significant differences. In the study sample, both upper. anterior and upper posterior facial heights were found to be significantly greater when comparisons were made with controls. These results indicate a more inferior location of the maxillary base in the study sample. Maxillary basal relations are unlikely to be affected by dentoalveloar changes, the dimensions of the upper face being determined more by genetic and airway considerations (Woodside and Linder-Aronson 1979) and this observed difference between control and sample categories is more likely to be due to age changes. A longitudinal study of craniofacial morphology associated with ageing in the third decade of life carried out by Sarnas & Solow (1980) provided results comparable to the present study, with an inferior displacement of the maxilla observed in successive age groups. It may be concluded that the difference between sample and control categories seen in the present study represents a continuation of this growth change further into adult life. However, sutural growth may be considered to be complete at the mean age of the control group (26.1 years), and thus growth in these regions of the upper face should not effect a significant change in upper facial height. Similarly, appositional growth alone would not be expected to produce the significant difference observed, and therefore a combination of sutural and appositional growth seems more likely. The alignment of the sutures separating the maxilla from the cranium is such that continued growth in this region would appear to effect a downwards displacement but there is no strong evidence that this is the case. Bjork & Skeiller (1977) have confirmed that a lowering of the maxilla occurs throughout the growth period, and the subsequent work of Sarnas & Solow (1980) together with the results obtained in the present study would indicate that an inferior displacement of the maxilla occurs with age throughout adult life. This change is probably due mainly to genetic considerations, as the dimensions of the upper face are unlikely to be significantly influenced by the presence of attrition. No evidence was found in the present study to indicate tooth wear had any effect on this component of the facial skeleton.

No significant differences regarding lower anterior facial height were identified between control and sample groups as noted above. This result was somewhat surprising, as many workers have reported smaller mean values of lower anterior facial height in cephalometric studies in subjects with attrition (Tallgren 1957, Murphy 1959b, 1968, Fishman 1976, Krogstad & Dahl 1985). However, in most of this work, the subjects used were anatomical specimens derived from primitive populations, and results obtained from these studies should be interpreted with caution when comparing them to the present study.

As noted previously, total facial height measurements were not found to differ significantly between the categories in the present study, and subjects from the study sample showed a greater mean value for upper facial height. Measurements of the difference in lower anterior facial height, whilst not statistically significant (p=0.068) would thus tend to indicate that in the study sample, under the influence of ageing and attrition, lower facial height occupies a lesser percentage of the total facial height when compared to controls. However, the greater mean value of upper anterior facial height in the study sample was less than the difference in tooth lengths between the control and study categories and **the results thus indicate that the more inferior position of the maxilla does not account for the similar measurements of lower facial height in both groups. Thus some compensation for the attritional tooth wear must exist in the sample group other than maxillary growth changes.**

Baer (1956), Tallgren (1957), Forsberg (1979) and Sarnas & Solow (1980), have reported a mean increase in lower anterior facial height with age continuing into the third decade of life, the greater part of this increase occurring within the first half of this decade. The results of the present study would indicate that vertical facial growth continues beyond the third decade but that the effects may be masked by intervening attritional processes. Begg (1977) has suggested that a continuing vertical growth of the lower face may be attributed to continual tooth eruption. Certainly, Ainamo & Talari (1976) have demonstrated that tooth eruption occurs in adults, and the work of Murphy (1959b) suggests that continual tooth eruption had a significant role in maintaining facial height in ancient man where attrition was prevalent and generally severe. Murphy (1959b) and Begg (1977) have thus suggested that the increase in facial height with age in modern man may be a result of less prevalent and less severe attrition. **The results obtained in the present study however, suggest that the increase in total facial height with age in normal subjects may also be due to vertical growth of the maxilla independent of attritional, as well as tooth eruption in the absence of wear.** In subjects exhibiting advanced attrition, both factors continue to operate and in a modern population, total face height may be maintained by these mechanisms.

(iii) Maxillary relations

Differences in the antero-posterior location of the maxilla with respect to the cranial base were also identified when control and sample categories were compared. Though the maxilla was found to be located inferiorly in the study sample, no change in its angulation to the cranial base was identified, in accordance with the observations of Forsberg (1979) and Sarnas & Solow (1980). The overall length of the maxilla at the basal level was observed to be significantly greater, and the maxillary base located more anteriorly relative to the cranial base in the study sample when compared to controls. This pattern follows the overall trend of maxillary growth direction (Israel 1973) and provides further evidence that maxillary growth continues beyond the third decade of life, and that this pattern of growth follows the general trend seen before and during the third decade.

An increase in maxillary basal length has been reported as an adult age change (Forsberg 1979) and the results of the present study support this finding. However maxillary length at the alveolar level was not found to differ significantly between control and sample categories. Sarnas & Solow (1980) have reported an increase in this dimension with age and it is thus possible that the influence of attrition has affected the results of the present study. The measurement of maxillary alveolar length involves a reference point on the maxillary alveolar base (ss),, and any dento-alveolar differences between the two categories due to attrition may have an effect on the location of this reference point. The results obtained suggest that the profile form of the maxillary alveolus in the study sample differs from that of the control, with the maximum concavity of the alveolar border being situated closer to the maxillary base. Thus the reference point ss is found higher and more posteriorly on the alveolar profile in the study sample (Figure 25,26) when compared with the control group. However, this different profile of the anterior maxillary border did not appear to be related to upper incisal angulation differences between the groups, and as such it is not possible to attribute the different morphology to the attritional process, and thus may represent a growth change.

Despite the antero-inferior location of the maxilla noted in the study sample, measurements describing maxillary prognathism were not found to differ significantly between control and sample categories This is due to the more anterior location of the point nasion and variations in the position of the reference point ss in the study sample.

The results also indicate that **the maxillary alveolus retains its relationship to the maxillary base despite the influence of age and attrition,** though the different alveolar profile identified in the study sample prevented measurements of maxillary alveolar length from differing significantly between the two categories. Mean plots obtained from the data (Figure 25, 26) clearly illustrate the differences in maxillary relations between the groups.

Whilst it is possible to attribute differences in the location of the maxillary base between the categories to age changes, the situation is less clear when considering maxillary alveolar relations. These are more likely to be influenced by the presence of attrition, occlusal factors and mandibular relations to the maxilla. However, the evidence provided by the present study suggests that attrition does not have major effects on the antero-posterior relationship of the maxillary alveolus to its base.

(iv) Dento-alveolar relations

As was expected, many significant differences in variables describing dento-alveolar relationships were identified when the control and sample categories were compared. The results obtained describe a smaller mean value of the distance from the tip of the upper central incisor to the maxillary plane in the study sample when compared to controls. No significant difference in the angulation of the upper central incisor to this plane was found when comparisons were made. This result demonstrates that attritional tooth substance loss results in a smaller mean value of dentoalveolar maxillary height in the study sample. The more forward position of the upper central incisors as described by Fishman (1976) was not seen, nor was the more upright position of these teeth as described by other workers (Begg 1977, Krogstad & Dahl 1985, Varrela 1990). This smaller maxillary dento-alveolar height in the study sample may be explained simply in terms of loss of tooth length through attrition, and **the results show that the upper central incisors maintain a stable relationship with the maxillary base despite the loss of tooth tissue.**

The labio-lingual widths of the incisal edges of both upper and lower central incisors were found to be significantly greater in the study sample when compared to controls, this result being readily explained by considering the morphology of the incisor teeth in saggital section. As an incisor becomes more progressively worn, clinical, anatomical and radiographic crown height become reduced, and the labio-lingual edge width increases. A high variance ratio was however recorded for variables describing upper incisor edge width (is_1-is_2).

Significant differences were also identified between the two categories with regard to measurements of overbite and overjet.

Analysis of the measurements indicates the presence of an edge to edge incisor relationship in the study sample, compared with the Class I incisor relationship present in the control category. The reduction of both lower and upper crown heights through attrition effectively removes the normal protrusive and lateral guidance pathways, and provided no protrusive guidance is provided by the posterior teeth, an edge to edge relationship of the incisor teeth may be achieved. In the present study, clinical observation of the edge to edge incisor contact was consistent throughout the sample. The association of the development of an edge to edge incisor relationship with advanced attrition has been reported by many workers (Murphy 1968, Fishman 1976, Begg 1977, Reinhardt 1983). The above do however note that advanced attrition is not always associated with an edge to edge bite. **The results of the present study do however, confirm that this relationship does occur in subjects with advanced attrition,** though high F-values were identified for the variable describing overjet (oj).

Lower incisor angulation was found to be smaller in the study sample when compared to controls, though the result did not achieve statistical significance at the 5% level (p=0.061), a finding which is in general agreement with that of Varrela (1990. This small difference is related to differences in mandibular morphology and position between control and sample categories, and the natural compensatory mechanisms of the alveolus in an effort to maintain incisal contact (Solow 1980).

The distance from the tip of the lower central incisor to the mandibular plane was not seen to differ significantly when the control and sample categories were compared. As lower incisor crown height is lost through attrition (as demonstrated radiographically by smaller mean values of tooth length and greater mean values of incisal edge within the study sample when compared with controls), the results indicate that some compensation has occurred in the study sample in order to maintain the relationship between the lower incisal edge and mandibular plane. **The results thus demonstrate that eruption of the lower incisors (possibly with differential alveolar bone growth) has occurred in the sample group to compensate for the loss of anatomical crown height through attritional processes.**

The values recorded for both upper and lower central incisor lengths were found to be significantly less in the study sample when compared to controls and the dimension recorded for the control group compared favourably with values recorded by Sicher (1960) when radiographic correction factors were taken into account.

The results demonstrated a 17.4% difference in upper incisor length between the categories, and a 13.0% difference in lower incisor length between the study sample and control group. These results are based on overall tooth lengths, and may not reflect the true percentage difference in anatomic crown height between the categories as apical apposition of cementum is likely to have occurred (Murphy 1959) which was not measurable on the lateral cephalometric radiograph.

The mean difference in tooth length between the groups for the upper central incisor was found to be comparable to the mean difference in maxillary dento-alveolar height between the two categories. **This result demonstrates that the upper incisors do not appear to significantly differ in their position in attritional states, either through eruption or differential alveolar growth.** In contrast, with the mean difference in lower incisor length between control and sample categories being greater than 3mm, and dimensions of mandibular dentoalveolar height being similar in both groups, **the results demonstrate that in the presence of attrition, the lower incisors come to be located at a higher position in the lower face.** This apparent eruption may be regarded as compensatory for attrition, and may occur either by tooth eruption alone, or in combination with alveolar growth. Murphy (1959b), has shown that the greater part of this effect is through eruption and cement apposition, with a smaller but significant contribution from alveolar bone growth and socket shallowing.

It was interesting to note that the upper incisors did not appear to erupt in the presence of such advanced wear. It is a common clinical observation in such cases of tooth substance loss that the upper incisors wear more rapidly. This may be related to the pattern of tooth tissue loss in that the anterior margin of the labial incisal edge becomes thin due to the initially downwards and forwards guidance on the upper incisor, and being more prominent, is subject to traumatic fracture of enamel by the lower incisors and extraneous objects. Thus the attritional wear through tooth to tooth contact is accelerated by microfracture and chipping of the upper incisal edge through trauma. Further research is however required to substantiate this hypothesis.

Studies of ageing in adult life have demonstrated an increase in lower facial height with age and this has been attributed to eruption of the teeth (Murphy 1959b, Begg 1977). However, this increase in lower facial dimension is relatively small in normal subjects, and age changes alone would not account for the large difference in lower incisor vertical position observed in the present study. Dahl & Krogstad (1982) proposed that eruption of the teeth was not the cause of an increasing vertical occlusal dimension with age, but rather that the teeth erupted to maintain occlusal contact in a lengthening lower face. In the present study, **the evidence suggests that true compensation for loss of tooth length has occurred as the dimensions concerned cannot be explained by age changes alone.** This observation thus supports the views of Krogstad & Dahl (1982) and Solow (1980) in that the teeth respond to the changing pattern of facial morphology, rather than effecting the changes themselves. Why the lower incisors should produce this result alone, rather than in conjunction with the upper incisors is however still unclear.

The results so far suggest that the total face height is maintained constant throughout adult life in the presence of attrition, by a process of age changes translating the maxilla downwards, partially compensating for incisor wear, the remaining compensation being due to eruption of the lower incisor teeth. The results suggest also that the differences in lower incisor position between control and sample categories represents a true compensatory eruption in response to attrition, rather than a wholly passive age related eruption, though this may play a small role in the overall morphological differences.

(v) Mandibular Relations

Many significant differences between control and sample categories were found when variables describing mandibular morphology were compared. Significant differences were identified in the relationships of the mandible to both the maxillary and the cranial base, suggesting that the shape and position of the mandible differs significantly from normal in the presence of advanced attritional tooth wear. No significant difference in the position of the mandibular condyle with respect to the cranial base was found when the two categories were compared. The development of an edge to edge incisor relationship may be a result of an anterior posturing of the mandible, particularly where there is loss of posterior support (Stern & Brayer 1975, Turner & Missirlian 1984), however in the present study, all patients in the study sample had radiographs taken in centric occlusion, with care being taken to ensure no such posturing occurred. The absence of difference in condylar position between categories confirms that the radiographs had been correctly recorded.

Murphy (1958), Granados (1979) and Richards & Brown (1981) have demonstrated changes within the temperomandibular joint in the presence of advanced attrition, and the similar locations of the condyle in both groups in the present study may represent a morphologic adaption to function in view of the prevalence of edge to edge incisor contact in the study sample. The presence and development of attrition in the study sample may lead to an anterior posturing tendency which influences mandibular morphology through growth of the condyle in order to mantain its relationship with the cranial base. Murphy (1958) commented that condylar growth may occur in response to functional attrition, and both Moller (1966) and Ingervall & Thilander (1974) have demonstrated correlations between muscular activity and facial morphology. **The results of the present study would thus indicate that growth at the condyle may therefore occur in the presence of this form of advanced tooth wear, possibly as a result of muscular anterior posturing.**

The results obtained by Varrela (1990) also suggest an anterior growth rotation of the mandible as being a major factor involved in the development of the edge to edge incisor relationship, with soft tissue stretching occurring as a result of adaptive mandibular posture. Such stretching may have an influence on this pattern of mandibular growth in a similar manner to that in which soft tissue stretching due to variations in head posture affects the facial growth direction (Solow & Kreiborg 1977, Varrel 1990). Thus the action of the soft tissues results in such a growth rotation of the mandible, and condylar growth may occur transforming the postural incisal relationship to a morphologic feature.

Mandibular base line length, ramus length and body length were all found to be significantly greater in the study sample when compared with controls. These observations indicate the presence of a significantly different overall mandibular morphology in subjects with advanced attrition, and these differences have not been reported previously as a feature of ageing.

Forsberg (1979) however reported an increase in the angulation of the mandibular line to the nasion-sella line with age. In the present study, the different mandibular morphology resulted in smaller values of this dimension in the study sample when compared to controls, together with a smaller mean value of mandibular base line angulation relative to the cranial base. A significantly more acute gonial angle was also identified in the sample category when compared to controls in accordance with the findings of Fishman (1976), Krogstad & Dahl (1985) and Varrela (1990). In addition to the different mandibular morphology seen in the study sample, mandibular prognathism was found to be significantly greater in the sample category when comparisons were made with controls. Accordingly, relative prognathism (ss-n-sm) was found to be significantly less in the study sample when these comparisons were made though a high variance ratio was calculated for this variable. **The overall difference in the mandibular morphology seen in the sample category thus appears to be that of lengthening and anterior rotation.** The greater mandibular base line length may be explained by condylar growth as above, but the smaller mean values for gonial angulation, mandibular plane and mandibular base line angulation are more likely due to both a reduction in body-ramus angulation and development of the gonial process postero-inferiorly.

In the present study, the subjects in the sample group demonstrated an edge to edge incisal relationship which may have been initially postural as discussed. This new mandibular posture may subsequently have influenced mandibular morphology through the necessary changes in muscular activity. Thus altered function of the muscles of mastication may result in development of the gonial angle, anterior mandibular growth rotation, reduction in mandibular plane angulation together with compensatory eruption of the lower incisor in response to the tooth wear. **It is interesting to note that the mandibular rotation and reduced gonial angulation present in the study sample were not associated with a reduced lower anterior facial height due to the different position of the lower incisors and maxillary growth pattern.**

The longer mandible seen in the study sample thus maintains the edge to edge incisal relationship, and results in greater values of mandibular prognathism as seen in the sample cateogry. Values recorded for mandibular prognathism in the study sample when compared to controls also indicate that **the mandibular alveolus retains its relationship with the mandibular base, also maintaining the edge to edge incisor relationship in the presence of attrition,** as smaller values for relative prognathism (ss-n-sm) were also observed in the study sample when compared with controls. Surprisingly, one variable describing relative mandibular prognathism (ss-n-pg) was not found to differ significantly between the categories, but this may be explained by differences in the vertical positions of the reference points and the more anterior position of nasion and the maxilla in the study sample.

Forsberg (1979) reported a posterior rotational growth of the mandible throughout the third decade of life, and Sarnas & Solow (1980) demonstrated a concomitant increase in anterior facial height during this period. In the present study, **the differences observed in mandibular morphology and its relations to the maxilla and cranial base in the study sample are thus clearly related to the presence of attrition in this category, as growth changes would not reasonably be expected to reverse their trends after the third decade of life.**

As reported previously, the point nasion was found to be located more anteriorly in the study sample, and the maxilla positioned antero-inferiorly when compared to controls, with no upper incisor tooth eruption was identified to compensate for attrition. The differences between control and sample categories with respect to lower incisal and mandibular relations reflect these observations, with an overall increase in body length and development of the gonial process being present, together with the apparent eruption of the lower incisors. The anterior teeth are positioned in an edge to edge relationship and the greater mandibular length and smaller mandibular plane/base line angulation are such that the lower incisors are positioned at a smaller angulation to the mandibular plane (although this did not reach the 5% level of significance). As mandibular prognathism was noted to be greater and relative prognathism smaller in the study sample on comparison to controls, it can be seen that **in the presence of attrition the maxilla and mandible do not maintain the same saggital relationship to each other, with a pre-normal occlusion being present in the attritional** state.

The differences observed in mandibular morphology between control and sample categories may help to explain the clinical appearance of patients with advanced attrition. The more protrusive mandible and higher position of lower incisors may give the appearance of "overclosure" when in reality no loss of vertical dimension has occurred.

(vi) Soft tissue relations

Analysis of the variables describing soft tissue morphology revealed many signficant differences when the control and sample categories were compared. These differences tended to reflect the hard tissue differences between the groups when comparisons were made.

The soft tissue differences that exist between normal subjects and those suffering from advanced dental attrition have not been reported previously and present new information for the study.

In general, no overall difference in the angle describing facial profile form was identified when comparisons between the two groups were carried out, though many individual elements of facial profile were found to differ significantly.

The vertical height of the base of the nose was not found to differ significantly on comparison of control and sample categories. These tissues are sufficiently remote from the dentoalveolar complex such that morphological hard tissue differences due to the presence of attrition in the study sample would not be expected to influence them. Growth changes in the upper face would however, be reasonably expected to have an effect on nose height and as greater values for upper anterior facial height were identified in the study sample when compared to controls it is surprising that no increase in nasal height was identified. Sarnas & Solow (1980) did find an increase in this dimension with age in a longitudinal study of adult age changes in the facial profile. However, the mean age of the oldest group in this study (25.6 years)was comparable to the mean age of the control group in the present study (26.1 years) and thus this study provides no informatin as to later age changes in this dimension. However, **the evidence provided by the present study would suggest that growth in the vertical height of the nose is complete by the end of the third decade of life**, and does not increase thereafter, despite the continued antero-inferior growth of the maxilla.

Nasal protusion was found to be signficantly greater in the study sample when compared to controls. Both Forsberg (1979) and Sarnas & Solow (1980) recorded a similar result with increasing age throughout the third decade of life. The results of the present study agree with this finding and indicate that a more **anterior location of the apex of the nose occurs with age throughout adult life.** This result is related to the more forward position of the anterior maxillary base as discussed in the results for the hard tissue analysis in the study sample. It is of interest that the more anterior location of the nasal tip did not result in differences between control and sample overall facial profile form angles. This is due to the similar more anterior location of the reference point of this variable on the soft tissue chin in the study sample. Thus, whilst the overall profile angle was similar when control and sample categories were compared, **in the study sample the soft tissue profile form was seen to be rotated about the tip of the nose with the lower facial reference points located more anteriorly (Fig 25,26).**

The length of the dorsum of the nose was similarly found to be greater in the study sample when compared to controls, corresponding to the more anterior position of the nasal apex in the sample category. This result also suggests that whilst the nose may be located in a more anterior position along with the maxilla in the study sample, **the soft tisue nasion reference point and the frontal soft tissue profile show few location differences when compared to controls.** This is to be expected, as these soft tissues lie over cranial and cranial base structures and are therefore less subject to age and functional influences. The hard tissue nasion reference point was however, found to be situated more anteriorly in the study sample when compared to controls, and it is unclear why the soft tissue point was not found to retain its relationship with the hard tissue point though this may be due to the thinning of tissues that is associated with the ageing process.

No difference in the vertical position of the nose was observed between control and sample categories, despite the more antero-inferior location of the maxilla in the sample group. This indicates that in addition to the relative stability of nasal height after the third decade, the nose retains its vertical relationship to the cranial base, despite the lowering of the maxillary base with age.

The variables describing upper lip profile showed significant differences when control and sample categories were compared. No significant difference in upper lip protusion was identified between the two categories, but the results showed a greater depth to the naso-labial curvature and a lesser degree of lip prominence in the study sample though high F-values were recorded for these variables. These results describe a flatter and less concave upper lip profile in this category when compared to controls and this may be attributed partly to the greater nasal protusion and partly to age changes in the lip tissue, such as loss of muscle tone. The absence of significant differences in upper lip protusion between the groups despite the more anterior location of the maxilla also indicates a smaller mean value of lip thickness in the study sample. Sarnas & Solow (1980) identified similar soft tissue changes with age and the results of the present study may be viewed as an extrapolation of these results beyond the third decade of life.

In addition to the loss of elasticity and muscle tone which accompanies ageing in the tissues, the thinner upper lip and flatter profile seen in the sample category may also be related to loss of lip support by the incisors, due to their smaller crown height through attrition and the absence of eruption to compensate for the tooth tissue loss.

The more inferior position of the maxillary plane within the facial skeleton as seen in the study sample, when considered along with the similar vertical position of the nose in both categories, also demonstrates the presence of a longer lip in the study sample when compared with controls. This observation confirms the results of Sarnas & Solow (1980) who described an increase in upper lip length with age. **It would thus seem that attrition may have more bearing on upper lip profile than length, with age related changes exerting a greater influence on upper lip vertical dimensions.**

Lower lip prominence was similarly found to be less in the study sample when compared with controls. This result when considered with that obtained for upper lip prominence indicates that **the horizontal position of the upper and lower vermillion borders of the lip relative to each other remains constant in both categories, irrespective of attritional or age changes** and thus the lip seal is maintained. As was expected from the results of the hard tissue analysis, lower lip protusion was found to be greater in the study sample on comparison with the control category, corresponding to the more anterior position of the hard tissue reference points on the anterior border of the mandible in the sample cateogry.

No significant difference was observed in the depth of the labio-mental fold when both categories were compared, suggesting that whereas the lower lip appears less prominent in the study sample, the labio-mental fold depth is similar in both groups due to a more protrusive soft tissue chin. **The results accordingly indicated greater values for soft tisue chin protrusion in the study sample when compared to controls, confirming this observation.** This

corresponds to the anterior positions of the hard tissue reference points in the study sample and may similarly help to explain the clinical appearance of "overclosure" when no loss of vertical dimension is actually present as determined radiographically.

Lower lip length was found to be significantly less in the study sample when compared to controls, and this result corresponds with the significantly greater mean upper lip length identified, **confirming that lip seal is maintained despite horizontal and vertical differences in soft tissue morphology.** It would thus appear that whilst the dento-alveolar height of the anterior mandible remains relatively constant despite attritional influences, **the heights of the lips remain partly independent of attritional status** and the lip contact position was accordingly found to be positioned inferiorly to the occlusal plane in the study sample when compared to controls though a high variance ratio was calculated for this variable. The overall pattern of differences in lip morphology between control and sample categories would thus suggest that **whilst attrition has a role in lip profile and saggital lip relations, ageing has more influence on the vertical dimensions of the upper lip.** Forsberg (1979) and Sarnas & Solow (1980) both reported an increase in upper and lower lip height with age together with an increase in lower anterior facial height, and it may be concluded that the results obtained in the present study with regard to lower lip length were influenced by the presence of severe attritional wear, as no greater values of lower anterior facial height were identified in the study sample. **Thus the length of the lower lip appears to be attrition dependent, through the effect of this tooth** wear on lower anterior facial height. The lip contact position would thus become more inferiorly situated with age in the presence of attrition, resulting in an increase in prominence of the lower incisor teeth, again contributing to the clinical appearance of "overclosure". Apparent reduction of lower facial vertical dimension is often reported as a clinical feature in cases of advanced attrition (Mack et al 1968, Hamilton & Whitehead 1968, Gankerseer 1987, Best 1987). The results obtained in the present study indicate why a patient may present with this appearance in the absence of loss of lower anterior facial height. The more prognathic mandible found in the study sample and the soft tissue differences observed between this sample and the control category give this clinical appearance.

C. DISCUSSION OF THE PATTERN OF ASSOCIATIONS BETWEEN FACIAL HEIGHT AND SELECTED VARIABLES DESCRIBING CRANIOFACIAL MORPHOLGY

In both the control and sample categories, associations were identified between facial height and selected variables describing craniofacial morphology. Facial height was divided into total, upper anterior and lower anterior components, and the variables describing craniofacial morphology were selected from the variables used in the analysis as being representative of mandibular morphology, incisal relations and soft tissue morpholgoy.

Correlation coefficients as a means of demonstrating associations between variables are only valid when the two sets of measurements form normal distribution curves. In the present study, all distributions were examined by tests for skewness and kurtosis to ensure valid comparisons were made. Correlation tests were applied to these data, though in view of the relatively small numbers in the groups, the results are interpreted with care.

Whilst many associations between variables were found in the control group, fewer associations were identified within the study sample. The reasons for this situation are not immediately clear but may be related to the wide age range in this category. However, the results suggest that there are few clearly defined patterns of craniofacial associations identifiable with respect to attrition. Such patterns do exist for normal subjects (Solow 1966), and the results of the present study are in general agreement with previous work in this field.

In the control group, greater values of lower anterior facial height were found to be associated with a less prognathic mandible and increased values of mandibular base line angulation, suggesting a backwards rotational growth pattern to the mandible in the control group. The results obtained in the study sample did not show any clear patterns of association, though a negative correlation was identified between lower facial height and relative prognathism, suggesting that subjects with attrition who do not have smaller values of lower facial height tend to have a more prognathic mandibular morphology. In common with the control group an association was found between lower anterior facial height and mandibular base line angulation, demonstrating that variations in lower facial vertical dimension may have effects on mandibular angulation as described.

In the control group, an association was identified between facial height and both overbite and lower incisal edge width. The results indicate that the association is primarily between lower facial height and these variables, with greater values of these dimensions being found together. Overbite is more likely to be related to vertical dento-alveolar development in the anterior segment (Foster 1982) and it is difficult to see how this association may be explained.

It is of interest that no significant correlations betwen facial height and incisal relations were found in the study sample. This is probably due to the wide age range of the sample and the small numbers involved, and further research in this area will be required to identify any associations which may exist. It seems probable that such correlations should be present, as many workers have noted variations in vertical face height due to varying degrees of attrition (Tallgren 1957, Murphy 1959b, 1968, Fishman 1976, Krogstad & Dahl 1985).

Correlation coefficients calculated for facial height and soft tissue morphology did however reveal strong associations between these variables in both control and sample categories. In the control group, the results indicated an association between greater values of facial height and both less prominent lips and a less prominent chin, with the lower lip border positioned behind the upper lip border. Facial growth patterns resulting in a longer lower face could be expected to produce this profile due to the position of the underlying skeletal and dento-alveolar structures, such as the less protrusive mandible seen to be associated with increased values of facial height.

In the study sample, smaller values for facial height were found to be associated with a more protruded and prominent lower lip, indicating that the differences in soft tissue morphology identified between control and sample categories represents a pattern of soft tissue alteration in response to changes in the vertical facial dimension through attrition and ageing. Interestingly, a marked positive association was identified between facial height and upper lip height in both categories, providing further evidence that upper lip length is age determined and less subject to dento-alveolar influences. Associations involving soft tissue variables are however influenced by factors which cannot readily be measured, such as individual variation, the present of subcutaneous fat and oral muscular tension (Forsberg 1979) and these patterns of association must be interpreted with caution.

D. CLINICAL APPLICATIONS AND FURTHER RESEARCH

1. Clinical Applications

The clinical aplication of the techniques developed for the study are primarily concerned with the use of cephalometric radiographs in the field of restorative dentistry. A system has been devised by which patients with severe dental attrition may be examined radiographically, and data describing their craniofacial morphology recorded on computer disc file.

A database of both normative and sample material has been established and is available for further research. Addition of material to this database may enable comparisons to be made between individual cases of attrition an both control and sample data. Using the analysis developed for the study, it is possible to qualitiatively and quantitatively assess the differences that exist between individual cases of attrition and both normative and sample data. This analysis may be used to assess loss of occlusal vertical dimension and overall hard and soft tissue profile form in order to assist diagnosis and treatment planning in the clinical situation.

Analysis of radiographs prior to and after treatment for advanced dental attrition may be carried out using the computer programmes modified for the study. This will enable qualitative and quantitative assessment of the effects of treatment on the hard and soft tissue morphology of subjects with attrition, and comparison of the post-treatment morphology with normal material.

Minor modifications of the analysis will enable the same assessments of morphological characteristics and post treatment changes in facial form in both complete and partial prosthodontic cases.

A method by which central incisor attrition may be recorded radiographically has been established. This method has been demonstrated to be reproducible and have only a small method error. This method of recording attrition will have a clinical application, but further research is required to evaluate this fully as a means of quantitative assessment of tooth wear.

Information obtained from the study also has clinical application, in that the results identify considerations that must be taken into account when planning treatment for individual patients with tooth wear. This is particularly important with regard to assessments of differences in vertical facial and occlusal dimensions. The results also indicate the differences in physical characteristics which may exist between cases of attrition and normal material, particularly those which give the appearance of 'overclosure' and these must be considered when planning treatment.

The use of an anterior bite plane in the treatment of cases of attrition is a common procedure (Renson 1975, Dahl 1975, Turner & Missirldian 1984, Dahl & Krogstad 1985, Devlin 1985, Charlton 1989), by which intrusion of the incisor teeth and eruption of the posterior teeth may provide interocclusal space for the placement of restorations after a period of wear (Dahl & Krogstad 1982, 1985, Devlin 1985). Intrusion of the incisor teeth has been demonstrated to occur during the use of these apliances by Krogstad & Dahl (1987), though it remains unclear from this study whether this effect occurs in the upper or lower teeth, or is evenly distributed between the two.

The results of the present study demonstrate an apparent eruption of the lower incisor teeth in the presence of advanced attrition, with no difference in upper incisal relations to the maxillary base being found. These results thus justify the use of an intermediate appliance to preferentially intrude lower incisors to provide occlusal clearance for the provision of restorations in the treatment of advanced attrition. Similarly, such an anterior bite plane could be used on a basis of intermittent wear to protect the restorations once fitted.

The results of the study have also identified those changes in facial form which may occur as a result of ageing beyond the third decade of life. Such age changes must also be considered during the diagnosis and treatment of advanced attrition.

Of particular importance is the apprent increase in upper lip length seen with age as indicated by the results of the present study. Attempts to restore incisal edges to the lip contact position in fixed or removable prosthodontics must be exercised with caution, as relying on this soft tissue variable as a reference may result in inappropriate incisor positioning, incisal contacts or occlusal plane angulation in order subjects. Similarly, the thinner upper lip identified in the presence of ageing and attrition must also be considered when determining the antero-posterior position of incisal restorations.

The methods used in the study and the information obtained from the subjects included may also be used in clinical undergraduate teaching. An understanding of the effects of both attrition and ageing on the facial skeleton is necessary in order for undergraduate students to have a complete knowledge of all factors involved when diagnosing and planning treatment for the ageing dentition.

2. Further Research

The results obtained in the study have identified certain areas in which further research is required either to elucidate the results obtained or evaluate the method for use as a diagnostic or interpretive tool.

As attrition is an integral part of ageing and the development of the occlusion, further research is required to evaluate the differences that may exist between normal and sample material in successive age groups with respect in particular to facial height in the presence of attrition. This will provide further information regarding changes that may occur in craniofacial morphology as ageing progresses. In addition, identification of such differences in craniofacial morphology between subjects showing varying degrees of severity of attrition is also necessary to further show how progressive attrition may influence craniofacial form.

Longitudinal investigation of sample material would also provide this information for individual cases.

Investigation is also required to determine the degrees of eruption and dentoalveolar growth which combines to produce the more superior position of the lower incisors in the study sample when compared to controls.

Further studies into the patterns of associations between craniofacial morphological variables in subjects with dental attrition is also required and may help to confirm the results of the study.

Radiographic assessment of attrition by cephalometric analysis has not been reported previously. It has been demonstrated that incisal edge attrition may be recorded accurately and reproducibly by this method, and further research is required to ascertain whether this technique may be employed in assessing incisor wear patterns and rates, and whether or not correlations between radiographic measurements or incisal attrition and vertical lower facial dimensions can be identified.

Head posture has been determined to have effects on occlusion (Mohl 1976) and alterations in occlusal vertical dimensions may have an effect on head posture (Root et al 1987). Further investigation into attrition, head posture and lower facial height would also provide further information regarding the widespread effects of attritional tooth wear on hard and soft tissue facial morphology.

SUMMARY OF FINDINGS

The purpose of the present investigation was to study craniofacial morphology in subjects with advanced dental attrition and in a control group. The material for the study was collected during the period 1988-89.

The study sample consisted of 35 patients with advanced dental attrition attending for consultant opinion. Only subjects who had not received any treatment for this tooth wear were involved in the study.

The controls consisted of 40 patients attending for orthodontic assessment, no patients with tooth wear or craniofacial deformity being included in this group.

Lateral cephalometric radiographs were obtained for all patients in the study. Reduction of radiation dosage was achieved by the use of high speed X-ray films and rare earth screens.

Method error tests were carried out by means of duplicate determinations for digitising linearity and cephalometric variables. The lateral cephalometric radiographs were digitised for each subject in the study and the data written to computer disc files. Examination of the validity of the digitised cephalometric variables was undertaken by an anlysis of the distribution of the deviations from normality for all the linear an angular variables using assessments of skewness and kurtosis. This enabled the data to be scrutinised for cephalometric point placement error and accuracy of location. A pen plot derived from the 51 reproducible digitised points was drawn for each subject and used as a further error check by comparison with the original tracing.

Tabulation of the results of the computer based analysis of craniofacial form for the control group and study sample subjects enabled statistical comparison to be made between the categories to detect significant differences between the study sample and control group.

A detailed knowledge of craniofacial hard and soft tissue morphology is useful for assessment and treatment planning for subjects with advanced dental attrition. The results of the study indicate that this form of severe tooth wear affects not only the teeth and alveolar bone, but also has more widespread influences on general aspects of craniofacial morphology.

The results demonstrated a more anterior position of nasion with advancing age, indicating that this reference point must be used with caution when comparing facial morphology in different age groups. This finding is in agreement with previous studies of facial morphology and ageing in the third decade of life.

Evidence provided by the study demonstrated that advanced attrition may affect the normal age changes that occur in total facial height a tendency towards reduction of this dimension, or a reduction of the normal increase in this variable with age being present.

Evidence was identified suggesting an increase in upper facial height with age after the third decade of life, following the general trends described for this dimension prior to this period. Lower anterior facial height was not found to be less in the study sample when compared to controls despite the loss of tooth tissue, and the results obtained indicated that loss of crown height through attrition is compensated for by age dependent growth in upper facial height, and attrition dependent eruption of the mandibular incisor teeth.

The results demonstrated a longer maxilla in the study sample when compared to controls, indicating that maxilla anteroposterior growth continues beyond the third decade of life, following the general trends before this period. The maxilla was found to retain its anteroposterior relationship to the cranial base in the presence of attrition, and the maxillary alveolus found to retain its relationship to the maxillary base despite the influences of ageing and attrition. The anterior border profile of the maxillary alveolus was however found to have its maximum concavity closer to the maxillary base in the study sample, when compared to controls. No evidence was found to suggest that this different profile was due to the presence of attrition, and use of this point in angular variables describing maxillary prognathism must therefore be viewed with caution when comparing different age groups.

The results also demonstrated that the upper central incisor maintains a stable relationship to the maxillary base despite the loss of tooth tissue through attrition, and the presence of an edge to edge incisor relationship was confirmed in the study sample.

No evidence was found to suggest that the upper central incisors erupt in the presence of attritional tooth wear, but the results indicated that the lower incisors appeared to erupt to compensate for the loss of tooth tissue, probably in conjunction with differential alveolar bone growth in the anterior mandibular alveolus. This apparent eruption of the lower incisors could not wholly be explained in terms of age changes and was considered to represent true compensation to altered morphology and function.

Both upper and lower incisor edge width were found to be greater in the presence of attrition when compared to normal material. The findings of the study thus indicated that total faical height appears to be maintained in the presence of attrition by a process of age changes translating the maxilla inferiorly, effectively compensating for upper incisor wear, and also by eruption of the lower incisor teeth. The results also suggested that the differences in lower incisor position between control and sample categories represents true compensatory eruption in response to attrition, rather than a wholly passive age related eruption, though this may play a small role in the overall morphological differences.

The results obtained in the study demonstrated the presence of a longer and anteriorly rotated mandible in the study sample, a feature which could not be explained by age changes, and was not found to be associated with any significantly smaller values of lower anterior facial height. The similar values for lower faical height found in the two categories were considered to be due to the maxillary growth pattern and more superior position of the lower incisor teeth in the study sample and the longer mandible and edge to edge bite seen in this sample was considered to be a morphological adaption to the developing attritional process.

With respect to soft tissue differences between control and sample categories, the evidence provided by the study indicated that growth in the vertical height of the nose is complete by the end of the third decade of life, but that an anterior relocation of the apex of the nose continues throughout adult life. A rotation of the overall soft tissue profile form about this point was seen in the presence of attrition, with the lower facial reference points of this variable being located more anteriorly in the study sample when compared to controls.

The soft tissue nasion point was not found to be more anteriorly located with age, and the nose was seen to retain its vertical relationship to the cranial base in the presence of ageing and attrition, despite the more inferior position of the maxillary base identified in the study sample when compared to controls.

The flatter upper lip profile and smaller mean upper lip thickness was seen in the study sample when compared to controls. The results suggested that while attrition has an influence on upper lip profile, the longer upper lip seen in the study sample on comparison with controls is more likely to be age related.

The upper and lower lips were seen to retain their saggital relationship at their contact point despite the influences of ageing and attrition lip seal was thus seen to be maintained despite differences in horizontal and vertical soft tissue morphology between the groups.

The heights of the lips were thus seen to be partly independent of attritional status, attrition being found to determine upper lip profile and saggital lip relations and upper lip length being age dependent. Lower lip height was however found to be attrition related, a shorter lower lip than expected being identified in the study sample. This smaller value for lower lip height was considered to be due to the absence of age related greater values of lower anterior facial height in the study sample.

The soft tissue chin was found to be more protrusive in the study sample when compared to controls, corresponding to the differences seen in hard tissue morphology between the categories. The overall soft tissue morphology seen in the presence of attrition and ageing was considered to contribute to the clinical appearance of 'overclose'.

For completeness, correlation tests were applied to the data but few marked associations between variables describing facial height and general aspects of craniofacial form were identified in either category. In the control group the results supported the findings of earlier research into the patterns of associations of variables describing craniofacial morphology. No clear pattern or associations betwen such variables was identified for the study sampe, though a marked association between facial height and upper lip height in both categories did support the finding that upper lip height is age related rather than attrition dependent.

However the results of the correlation tests did not reflect any possible co-ordinating mechanism that may influence facial morphology in the presence of attrition after the third decade of life.

CONCLUSION

The use of cephalometric radiography and computer based analysis of linear and angular variables of craniofacial morphology in the field of restorative dentistry has been demonstrated. Error testing by means of duplicate determinations has shown this method to be both accurate and reproducible.

Recordings of cephalometric data describing craniofacial morphology in subjects with advanced dental attrition were obtained for comparison with a control group. Statistical analysis of these results has demonstrated significant differences between control and sample categories for variables of both hard and soft tissue facial form.

Interpretation of these differences indicates that advanced dental attrition has widespread influences on facial morphology, and that facial growth changes continue throughout adult life.

The results obtained support the use of anterior bite plane appliances in the treatment of advanced attrition, and indicate the hard and soft tissue differences from normality which may contribute to the clinical appearance of "overclosure" and should be taken into consideration when diagnosing and planning treatment for this form of tooth wear.

APPENDIX

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19th December 1988

Mr. A.J.R. Crothers,
Registrar,
Dental Hospital,
Chambers Street.

Dear Andrew,

Your request for ethical approval for your DDS thesis has been supported by two members of the Lothian Area Dental Ethical Committee. You may therefore proceed with this study and approval will be homologated at the next meeting of the full committee.

Yours sincerely,

Professor J.C. Southam.

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Your ref:
Our ref:
If calling ask for:
Ext:

28th November 1988

Dear Mr. Crothers

Thank you for informing me about your research project in subjects with dental attrition. I am perfectly agreeable for any of my patients in this department to be included in this study, and I would be interested to learn of your findings in due course.

Yours sincerely

Dr. P.D. Callis
CONSULTANT

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FIGURE 25

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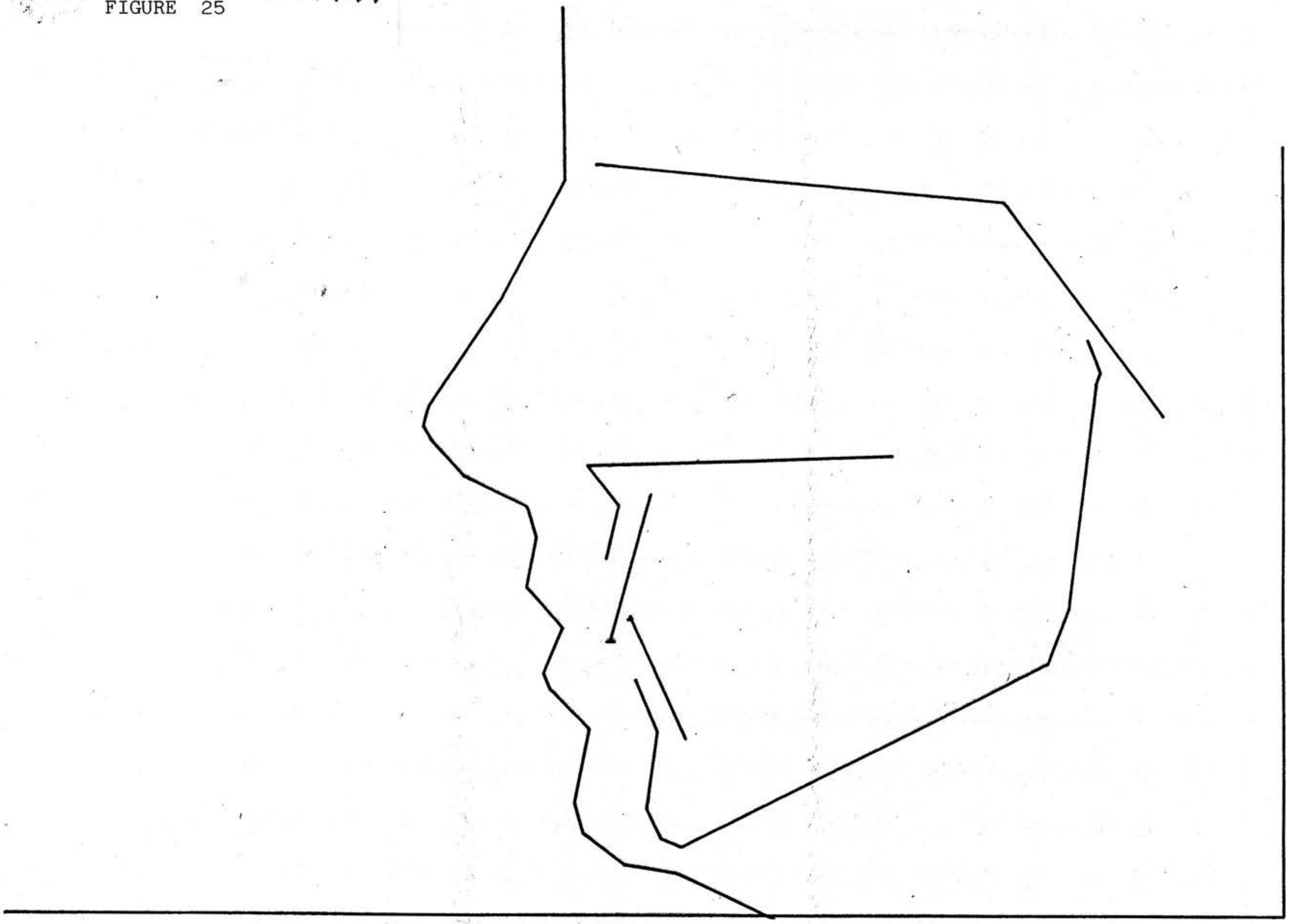

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FIGURE 26